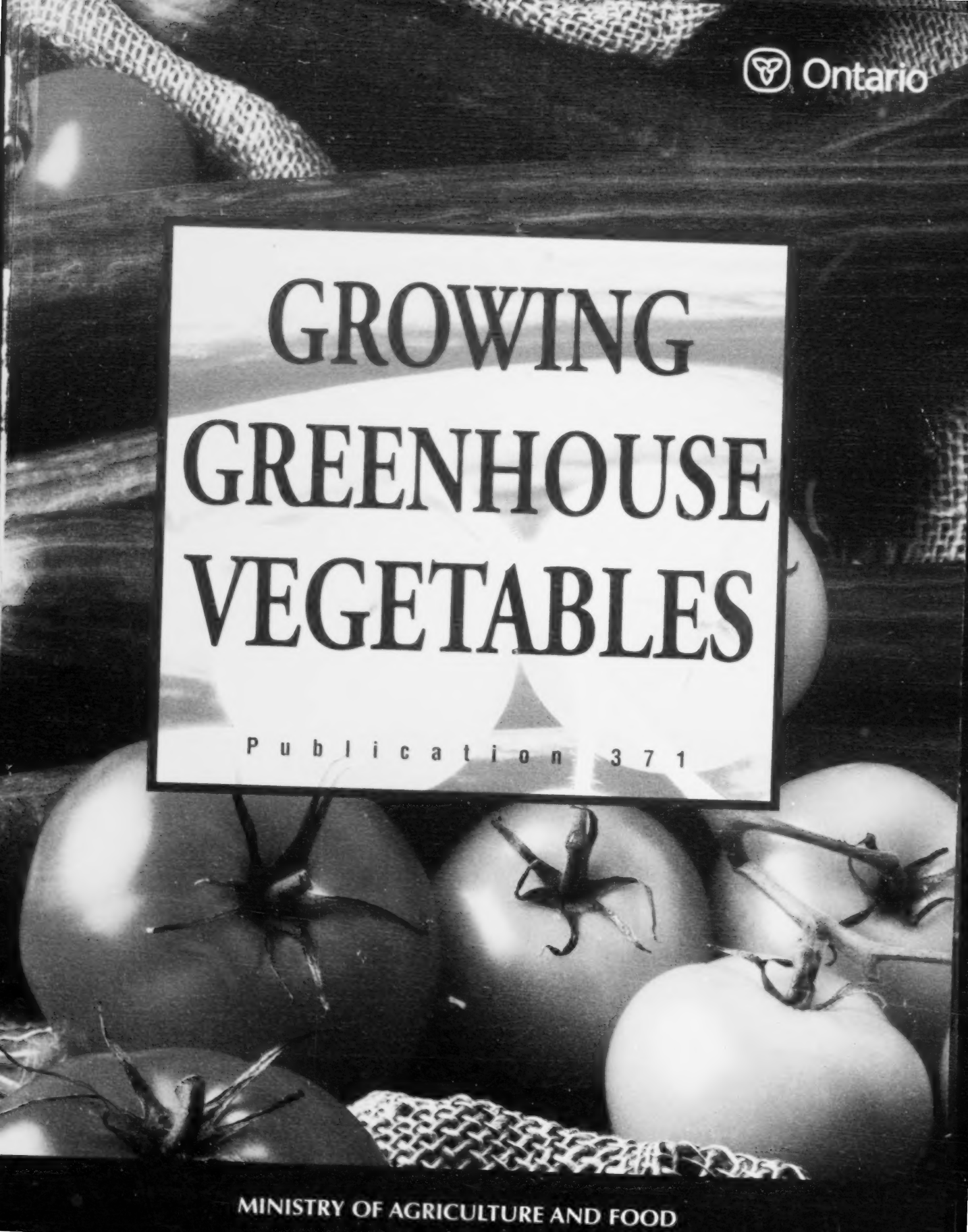

Ontario
GROWING
GREENHOUSE
VEGETABLES
Publication 371
MINISTRY OF AGRICULTURE AND FOOD

Recycle old editions of this publication. Each year the appropriate working group of the Ontario Pest Management Research and Services Committee reviews the pesticides listed in this publication. To the best knowledge of the committee, at the time of printing, all of these pesticides were:

- federally registered
- reviewed by the Ontario Pesticides Advisory Committee (OPAC)
- classified by the Ministry of the Environment as of November 2004.

The information in this publication is general information only. By printing this publication, the Ministry of Agriculture and Food does not offer any warranty or guarantee, nor does it assume any liability for any crop loss, animal loss, health, safety or environmental hazard caused by the use of a pesticide mentioned in this publication.

The pesticide product label is a legal document. It is against the law to use the product in any other way. You must also use all pesticides in accordance with the Pesticides Act and Regulation 914, administered by the Ontario Ministry of the Environment.

This publication lists a number of brand names of pesticides. This is for your convenience only. It is neither an endorsement of the product nor a suggestion that similar products are ineffective.

Consult each product label for specific information such as how to use the product safely, hazards, restrictions on use, compatibility with other products, and the effect of environmental conditions. Weather and other factors can influence the effectiveness of pesticides and the likelihood of crop injury, compatibility with other materials and the effect of environmental conditions.

Federal Registration of Pesticide Products

The Pest Management Regulatory Agency (PMRA) of Health Canada grants registration of pesticide products for use in Canada based on evaluation of scientific data to ensure that the product has merit and value, and the human health and environmental risks associated with its proposed use are acceptable.

1. **Full Registration**
   Pesticide registrations are normally granted for a period of five years, subject to renewal.
2. **Temporary Registration**
   Temporary registration may be granted for a period not to exceed one year, where the registrant agrees to produce additional scientific or technical information, or the pesticide is used for emergency control of a serious pest outbreak.

Maximum Residue Limits

Health Canada has established maximum residue limits (MRLs) for pesticides. Processors or retailers may demand more restrictive limits. Growers should seek advice of their intended market as to which restrictions or limitations apply. Keep accurate and up-to-date records on pesticide use in each crop.

Supplemental Labels

You MUST obtain a supplemental label and follow all the label directions when PMRA approves new uses for a registered pesticide that do not appear on the current label.

Examples of when you must use a supplemental label include:

- **Temporary Registrations for Emergency Use**
- **Minor Use Label Expansion** (new label statements for crops that do not already appear on that product label)

You can obtain a copy of a supplemental label from the pesticide manufacturer or pesticide vendor, the grower association that sponsored the emergency registration or minor use, from OMAF or PMRA's Pest Management Information Service.

For more information on the federal registration status check the PMRA web site at *www.hc-sc.gc.ca/pmra-arla* or call 1-800-267-6315.

Regulation of Pesticides in Ontario

The Ministry of the Environment is responsible for regulating pesticide sale, use, transportation, storage and disposal in Ontario. Ontario regulates pesticides by placing appropriate education, licensing and/or permit requirements on their use, under the Pesticides Act and Regulation 914.

All pesticides must be used in accordance with requirements under the Pesticides Act and Regulation 914. The act and regulation are available on the e-laws web site at *www.e-laws.gov.on.ca* or call Publications Ontario Toll-Free number: 1-800-668-9938 or 416-326-5300.

Classification of Pesticides into "Schedules"

The Ontario Pesticides Advisory Committee (OPAC) is responsible for reviewing and recommending to the Ministry of the Environment, the placement of pesticide products into one of six schedules used to control sale and use. Once approved by the Ministry of the Environment, classified products are posted on the OPAC web site: *www.opac.gov.on.ca*. For more information call OPAC at (416) 314-9230.

Licensing and Certification Requirements for Pesticide Users

You must be a certified grower or licensed exterminator to buy and use Schedule 1, 2 and 5 pesticides.

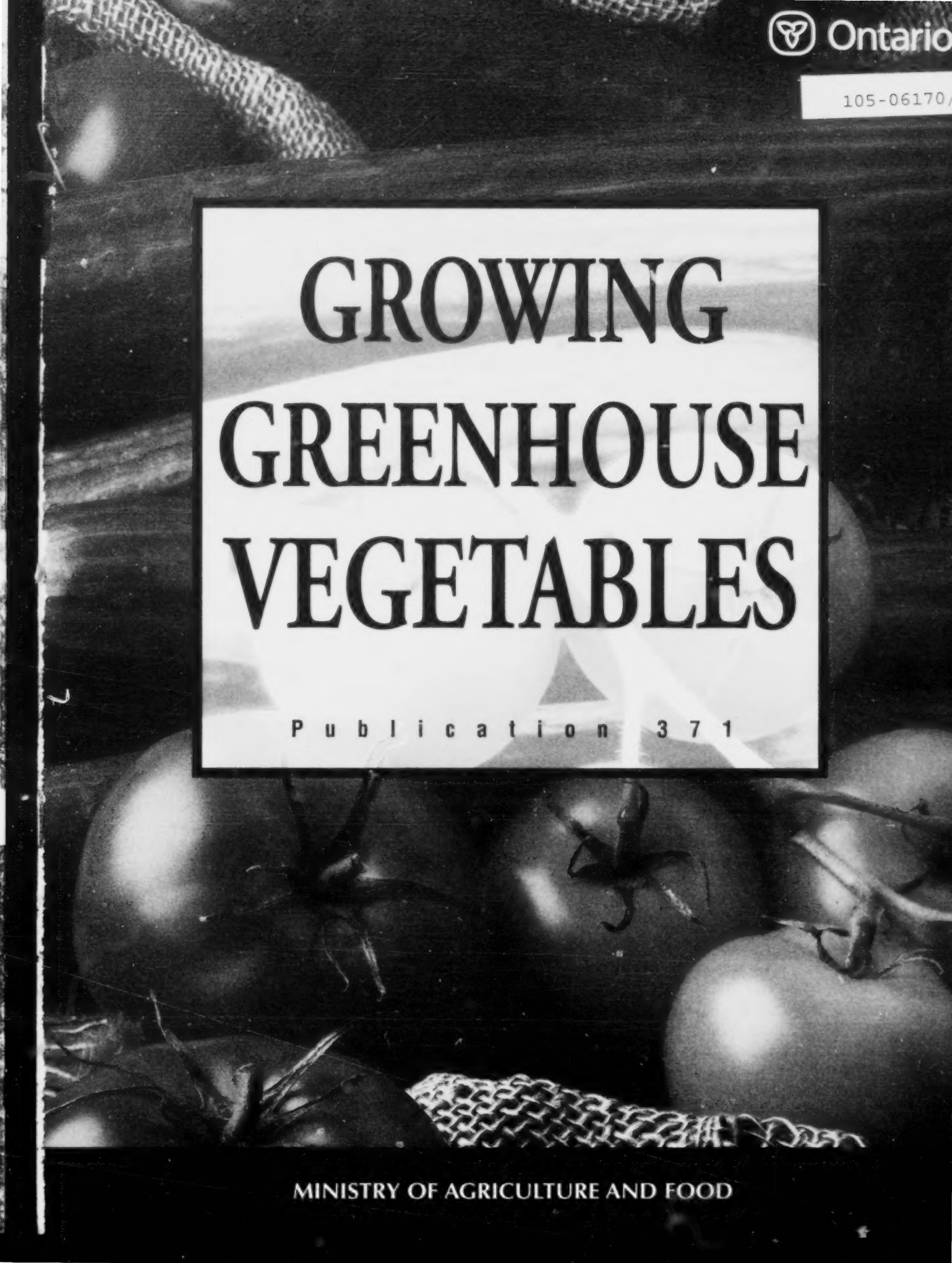
Requirements for Growers and their Assistants

For information about certification for growers and training for assistants refer to Chapter 1 of this publication or check the Ontario Pesticide Education Program web site at *www.ridgetownc.uoguelph.ca/opep/* or call 1-800-652-8573.

Requirements for Commercial Applicators and their Assistants

For information about exterminator certification and licensing and technician training refer to Chapter 1 of this publication or check the Ontario Pesticide Training and Certification web site at *www.ridgetownc.uoguelph.ca/optc* or call 1-888-620-9999.

Cette publication est aussi disponible en français.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Be Aware of Ontario's Nutrient Management Act and Other Legislation

The provincial Nutrient Management Act (NMA) regulates the storage, handling and application of nutrients that could be applied to agricultural crop land. The objective is to protect Ontario's surface and groundwater resources.

Please consult the regulation and protocols for the specific legal details. This publication is not meant to provide legal advice. Consult your lawyer if you have questions about legal obligations.

For more information on the NMA, call the Nutrient Management Information Line at 1-866-242-4460, e-mail: nman@omaf.gov.on.ca or visit the web site: www.omaf.gov.on.ca.

Publications and Factsheets are continually being updated, so please ensure you have the most recent version.

Need technical or business information?

Contact the Agricultural Information Contact Centre at: 1-877-424-1300 or ag.info@omaf.gov.on.ca

Looking for greenhouse production recommendations on the Internet?

www.omaf.gov.on.ca

It's one-stop shopping for Factsheets, articles and photos regarding the production and maintenance of Ontario's greenhouse crops. (or call us at 1-888-466-2372 to receive by fax/e-mail)

Acknowledgements

The recommendations contained in this publication have been prepared in consultation with:

- Ontario Horticultural Crops Research & Services Committee
- Ontario Pest Management Research & Services Committee
- Ontario Horticulture Crops Soil Management Research & Services Committee
- Individual growers, research personnel and agribusiness.

Cover photo courtesy of Ontario Greenhouse Vegetable Growers.

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1. Precautions with Pesticides

Pesticide Regulations

You must report all major spills, fires or thefts involving pesticides to the Ontario Ministry of the Environment at 1-800-268-6060. (Regulation 914, s. 29)

Pesticide Schedules in Ontario

The Ontario Ministry of the Environment reviews each pesticide product offered for sale in Ontario and classifies it into one of six groupings called Schedules.

Certification and Training Requirements

You must be a certified grower or a licensed exterminator to buy and use Schedule 1, 2 or 5 pesticides. Assistants may also use these pesticides if they are trained and supervised as required.

Pesticide Certification for Ontario Farmers

Regulation 914 of the Pesticides Act requires that agriculturalists (growers) be certified to buy and use Schedules 1, 2 or 5 pesticides on land they farm. To become certified, agriculturalists must:

- attend the Grower Pesticide Safety Course (GPSC) and successfully complete the examination, and
- meet the definition of an "agriculturalist" as defined by Regulation 914 under the Pesticides Act (i.e., use farmland for agricultural or forestry production that falls within the farmlands property class under section 7 of the Ontario Assessments Act), and
- be at least 16 years of age.

TABLE 1–1. Pesticide Schedules

Schedule	Who Can Use It	Pesticide Characteristics
1	• licensed exterminator • certified grower • only with approved permit	very toxic very persistent highly mobile
5	• licensed exterminator • certified grower • assistant agriculturist under supervision	very toxic very persistent highly mobile less toxic or less persistent alternative not available
2	• licensed exterminator • certified grower • trainee or technician under supervision (some restrictions apply) • assistant agriculturist under supervision	toxic persistent moderately mobile
3	• licensed exterminator • certified grower • trainee or technician • consumer	moderately toxic moderately persistent slightly mobile
4	• licensed exterminator • certified grower • trainee or technician • consumer	low toxicity non-persistent non-mobile containers < 1 kg < 1 L
6	• licensed exterminator • certified grower • trainee or technician • consumer	low toxicity non-persistent non-mobile containers > 1 kg > 1 L

Training for Agricultural Assistants Using Schedule 2 or 5 Pesticides

All assistants must have formal pesticide safety training, recognized by the Ministry of the Environment, before they can handle or use Schedule 2 or 5 pesticides under the supervision of a certified grower.

- This applies to all assistants, including family members, farm employees and seasonal workers.
- Trained assistants do not have to write an exam.
- Trained assistants must be 16 years of age or older.
- There are two training options for assistants. Assistants can:
  - attend a Grower Pesticide Safety Course and not write the certification examination, or
  - attend an on-farm training session presented by a qualified trained assistant instructor.
- For more information and a listing of Grower Pesticide Safety Course sessions and locations, check the Ontario Pesticide Education Program web site at www.ridgetownc.uoguelph.ca/opep.
- To register for a Grower Pesticide Safety Course anywhere in Ontario, or for information about trained assistants:
  - call: 1-800-652-8573
  - fax: (519) 674-1589
  - e-mail: opep@ridgetownc.uoguelph.ca.

Certification and Licensing for Commercial Pesticide Exterminators

For updates to training requirements under Regulation 914 of the Pesticides Act, refer to the Ministry of Environment web site at www.ene.gov.on.ca or phone 1-888-565-4923.

If you plan to apply pesticides as a business, you must be a licensed exterminator.

This includes farmers who custom-apply pesticides for other farmers and charge a fee for this service. Licensed exterminators who are self-employed must hold an operator licence as well as the appropriate exterminator licence. Exterminator licences are valid for five years.

To become a licensed exterminator, you must:

- complete a home study course and certification exam through Ridgetown College, University of Guelph, **and**
- send proof of certification (letter of successful completion of the exam(s)) and a fee to the Ministry of the Environment to obtain your exterminator licence.

Training for Technicians Working as Assistants to Licensed Exterminators

Assistants to licensed exterminators must become technicians to mix, load or apply all Schedule 3, 4 and 6 pesticides and most Schedule 2 pesticides (some restrictions apply), under the indirect supervision of a licensed exterminator. Technicians cannot mix, load or apply Schedule 1 or 5 pesticides. Technician cards are valid for two years.

To become a technician, you must:

- complete an MOE-approved academic course and exam, **and**
- complete practical training with a licensed exterminator.

For more information about certification and licensing requirements for licensed exterminators and training for technicians, contact Ontario Pesticide Training & Certification:

- tel: 1-888-620-9999
- fax: (519) 674-1585
- web site: www.ridgetownc.uoguelph.ca/optc

General Precautions

Always read the label first!

- **before you buy a pesticide**
- **before you begin to use a pesticide**
- **before you store a pesticide or dispose of it**

Learn about the health hazards and toxic properties of the pesticide you are using. Consult the product label, Material Safety Data Sheet (MSDS) or manufacturer for this information. Check the company web sites for MSDS information.

Protect Yourself When You Use Pesticides

- **Make sure someone knows** where you are working, what pesticides you are handling and how long you expect the job to take.
- **Post emergency numbers**, including the Poison Information Centre and Spills Action Centre near all of your telephones.
- **Keep a list of the names and the Pest Control Products (PCP) Act registration numbers** of all the pesticides you handle. Keep a file of the pesticide label booklets for all the products you use. Make sure your co-workers and family members know where this list or file is in case of an accident.
- **Have plenty of clean water, soap and paper towels — and an extra set of gloves and coveralls — nearby at all times** in case pesticide contaminates your clothing or skin.
- **Wear the correct protective clothing and equipment, and be sure that all items are clean and in good repair** before you put them on.
- **Never smoke, chew tobacco, eat or drink when you handle pesticides.** Never carry tobacco or food in your clothes — and never leave tobacco, food or beverages in areas where you handle or store pesticides.
- **Change your clothes and wash your hands and face before you eat, drink or smoke.**
- **Wash your hands before you use the toilet, as well as after.** The skin in your groin area absorbs pesticides very easily.

Protect Other People, Livestock, Pets, Water Sources and Sensitive Crops

- Buy and store only what you need.
- Prevent drift.
- Keep pesticides out of water sources.
- Clean up spills quickly and safely.
- Dispose of containers and waste pesticide safely.

Human Health

Risks of Pesticide Use

Each time you handle a pesticide, you are at some risk. The amount of risk depends on two things — the toxicity of that pesticide and your exposure to it.

Risk = Toxicity x Exposure

Toxicity

Toxicity is a measure of how harmful or poisonous the pesticide is. There are two types of toxicity:

- **Acute toxicity** – the toxic response that results from a **single exposure** to the pesticide. The symbols and words on the front panel of a pesticide label give you information about the acute toxicity.
- **Lethal dose 50% (LD_{50})** is a measure of acute toxicity. It is the dose (mg of product per kg of body weight) that will kill 50% of the test animals within a stated period of time (24 hours–7 days). Those products with low LD_{50} ratings are highly toxic. (See Table 14–1, *Insecticide and Miticide Toxicity and Classification*, p. 123 and Table 14–2, *Fungicide Toxicity and Classification*, p. 124.)
- **Chronic toxicity** – the toxic response that results from **repeated exposures** to small doses of a pesticide over a longer period of time. These toxic effects may not appear for months or years after exposure to the pesticide. The symbols on the label do NOT give information about the chronic toxicity of the product. Use protective clothing and equipment to help reduce exposure and the risk of chronic effects.

Cholinesterase Blood Tests

Organophosphorus and carbamate pesticides can affect your nervous system. These pesticides can change your serum and red blood cell levels of an enzyme called acetyl cholinesterase. Your body uses this enzyme to transmit messages through your nervous system. If your cholinesterase levels fall, you can experience symptoms including trembling, twitching, blurred vision, difficulty breathing and heart difficulties.

If you use any of the pesticides listed in the pesticide table on page 4 on a regular basis you should have regular cholinesterase blood tests. Your family doctor can

arrange these tests; they are covered by OHIP. **Have your first test before you begin to handle these pesticides.** That will show the baseline (normal) cholinesterase level for your body. During the spray season, if you are spraying organophosphorus or carbamate insecticides regularly for several weeks, you should have a cholinesterase blood test every **7–10 days**. If your cholinesterase level drops to below one-half of your baseline level, then you are showing signs of pesticide poisoning and **you must remove yourself from exposure** to these pesticides until your cholinesterase level returns to normal.

Common Name (active ingredient)	Trade Name
endosulfan	Thiodan, Thionex
malathion	Malathion
naled	Dibrom
propamocarb	Previcur

Exposure

Exposure is a measure of the contact you have with the pesticide. You can be exposed to the pesticide in three ways.

- **Dermal exposure** occurs through your skin or eyes. The amount and rate of pesticide that may be absorbed depends on several things, including:
  - your skin condition. If your skin is moist, or if you have rashes, broken skin or scratches, pesticide will be absorbed more easily.
  - the part of your body that is exposed. Your eyes, genital area, scalp and ear canals absorb pesticides at a higher rate than your hands or arms. Your eyes absorb pesticides at a rate of 100%.
- **Respiratory exposure (inhalation)** occurs when you inhale small spray particles, dust, gases or vapours.
- **Oral exposure** occurs when a pesticide enters your mouth or you swallow a pesticide.

Pesticide Label Information

Check the label for special warnings about eye and skin hazards. The front panel of the pesticide label may also contain warnings that the product is corrosive to eyes, or is a skin or eye irritant.

Read and Follow Pesticide Label Information

Know the Hazard Symbols and Words

Learn these symbols and words. They could save your life.

Four important symbols and words show the potential hazards of pesticides.

Hazard Symbol				
Signal Word	Poison	Corrosive	Flammable	Explosive

The hazard symbol will always appear inside one of the shapes shown below. These shapes and their warning words tell you the degree of hazard of the pesticide. The greater the number of sides to the shape, the more hazardous the product.

Warning Symbol			
	Triangle = low hazard (3 sides)	Diamond = moderate hazard (4 sides)	Octagon = high hazard (8 sides)
Signal Word	Caution	Warning	Danger

Check the label for special warnings about eye hazards and skin hazards. The front panel of the pesticide label may also contain warnings that tell you the product is corrosive to eyes, or is a skin or eye irritant.

Re-Entry Periods

Re-entry period is the minimum amount of time that must pass between the time the pesticide was applied and the time that workers can go into the crops without wearing personal protective equipment. If workers enter treated areas without wearing protective equipment too soon after pesticides have been applied, they may experience poisoning. Such poisoning can result from handling treated plants or from inhaling pesticide vapours. Always check the label for instructions for re-entry intervals. If such information is not available on the label, then check with the product distributor.

Days to harvest (pre-harvest) intervals

The pre-harvest interval is the minimum number of days that must pass between the last application of a pesticide and harvest. Pre-harvest intervals are required by law and should be observed to prevent harvesting of products with residues that exceed the maximum residue limits (MRL). Always check the label for instructions for pre-harvest intervals. If such information is not available on the label, then check with the product distributor.

Total Number of Applications

Some product labels will state the total number of applications of that pesticide that can be made during a growing season. These limits prevent crop damage, soil residues or pest resistance.

First Aid

Always protect yourself from injury first. Don't become another victim. Always put on protective clothing and equipment before you enter a contaminated area or handle a contaminated victim.

Check to see if the victim is breathing.

If the victim is not breathing:

- Straighten the victim's airway and check for breaths.
- If the victim does not begin to breathe, administer artificial respiration until the victim begins to breathe on his or her own.
- Do not contaminate yourself, especially if the victim has pesticide or vomit around the face or mouth. Use a face shield airway with a one-way valve. Do not breathe the exhaled air from the victim.
- Perform CPR if the victim's pulse disappears. You should only perform CPR if you are trained to do so.

If the victim is breathing, but unconscious:

- Place the victim in the recovery position (on the side with the head turned slightly to one side). If the victim vomits, try to keep the airway clear.
- **Stop the exposure to the pesticide.** Move the victim away from the contaminated area. Remove all contaminated clothing. Use soap and water to wash any skin exposed to the pesticide.
- Check the Four Basic Facts:
  - **What?** Identify the pesticide. Look for the label, container or leftover pesticide.
  - **How much?** How much product was the victim exposed to?
  - **Where?** How did the pesticide enter the body? Did it enter through the mouth, skin/eyes or lungs?
  - **When?** How much time has passed since the victim was exposed to the pesticide, and how long was the exposure? Were the symptoms immediate or did the poisoning occur as a result of using the pesticide over a longer period of time?

Don't waste time. If you can't answer these questions quickly, be ready to tell emergency personnel whatever you can.

- Call an ambulance or the Poison Information Centre.
- Start the first aid treatment appropriate for the route of entry.
- Make sure the patient gets medical attention. First aid is not a substitute for professional medical help.

Emergency Procedures for Pesticide Poisoning and First Aid Information

Refer to the inside back cover.

If symptoms of illness occur during or shortly after handling a pesticide, go to a hospital. Take the pesticide label, MSDS sheet or pesticide container with you. Do not transport the container in the passenger compartment of the vehicle. Refer to the Emergency Procedures for Pesticide Poisoning on the inside back cover.

Protective Clothing and Equipment

Choose and Wear the Appropriate Protective Clothing and Equipment

Make sure your protective clothing and equipment:

- is what you need for the job
- fits properly and
- is clean and in good repair and working condition.

The protective clothing and equipment you will need depends on the:

- pesticide you are using — Read the precautions section of the label to know what to wear.
- job you are doing — For example, you need more protection when you handle concentrated pesticide or when you mix and load your sprayer.
- type of application — For example, enclosed space or air blast sprayer applications made with open tractors require more equipment.

Each person who is working with pesticides needs **his or her own** set of protective clothing and equipment. Consult the technical expert at your safety supply company to make sure that you purchase the appropriate equipment and that it fits the user.

For **ALL** pesticides, always wear:

- A water-repellent hat, such as a hard hat or waterproof rain hat. Do not wear hats made from cloth.
  - Sometimes you need to protect your entire head and neck, for example, if you apply pesticides in a greenhouse, apply dusty formulations or use an air-blast sprayer. In these situations, wear a hood or hat that protects your ear canals. Do not wear hats made from cloth.
  - Baseball-style caps absorb pesticides and are not safe.
- Long pants and a shirt with long sleeves or a coverall.
  - Coveralls can be reusable or disposable. Reusable coveralls are normally cotton or polyester and should be tightly woven. Disposable coveralls should be designated for pesticide use.
  - Water-resistant coveralls are preferred because cotton, denim and cotton/polyester pants cling to the skin if they get wet, increasing the risk of dermal exposure.
- Chemical-resistant gloves (unlined).
  - Use neoprene or nitrile gloves (PVC), unless the label states otherwise. Do not wear rubber gloves, as many pesticides can break down the rubber material. Wear your gloves under your sleeves with the top cuffed.
- Chemical-resistant boots (unlined).
  - Wear your pant legs over your boots to prevent pesticide from running down inside your boots.

Read the label. It will describe what extra protective clothing and equipment to wear. For some pesticides you may also need to wear:

- goggles
  - Use safety goggles with indirect vents so that splashes do not enter your eye. Regular eye glasses do not provide complete protection. Never wear contact lenses when you handle pesticides.
- face shield
- chemical-resistant apron
- respirator
  - A respirator is a unit that covers your mouth and nose to prevent spray droplets, small particles and vapours from getting into your lungs. **A dust mask is not a substitute for a pesticide respirator.** Make sure you use cartridges and pre-filters that protect you against organic vapours. For more information about respirators, refer to the Grower Pesticide Safety Course Manual, Ridgetown College, University of Guelph.

- You may need more protection, such as canister gas masks or a self-contained breathing apparatus (SCBA) when you apply:
  - any pesticide in an enclosed area
  - fumigants, gases, vapours or smokes.

When you work with fumigants, gases or vapours or when you apply any pesticide in an enclosed area, ALWAYS wear a respirator.

Safety Supply Companies

Consult the safety supply companies of your choice for help in selecting your protective clothing and equipment. (See Table 1–2, *Safety Supply Companies in Ontario Providing Protective Clothing and Equipment*, p. 8.)

Care of Protective Clothing and Equipment

- After you complete the spray operation, clean all protective clothing and equipment.
- Never let children, pets or livestock come in contact with contaminated clothing or equipment. Also make sure that they cannot come into contact with the puddles of water left over from cleaning your equipment.
- **Wash your gloves with soap and water and leave them on** to remove your other protective clothing and equipment.
- Always remove protective clothing and equipment outdoors. If a granular pesticide was used, shake the clothing outdoors in a safe place, emptying pockets and cuffs.
- Throw out clothing that has been contaminated by spills of highly toxic or concentrated pesticide. Place clothing in a plastic bag and take it to a landfill site.
- **Coveralls and other spray clothing must be washed separately from other clothes.** They should be washed after each use. Place them in a plastic bag and keep them separate.
- With your hands still protected by gloves, wash protective equipment. Wash the inside and outside of your goggles, hat, boots and any water-repellent clothing in warm, soapy water, rinse well and let them air-dry.
- Remove the cartridges and pre-filters from the respirator.
- Discard cartridges, canisters and filter pads when breathing becomes difficult, or when you notice a pesticide taste or odour, or at the interval set by the manufacturer.
- Make a note of the date the cartridge is first used.
- Remove cartridges and filter pads from the face piece and store in clean, sealed plastic bags.
- Wash the face piece in warm soapy water, rinse thoroughly and dry in a well-ventilated area. Air-drying prevents damage to the inlet and outlet valves.
- Never use alcohol or other solvents for cleaning, as they will damage the rubber and plastic.
- Next, wash the outside of your boots and gloves with soapy water and remove them.
- After removing boots and gloves, wash them inside and out with detergent and water, rinse thoroughly and dry in a well-ventilated area.
- Place all dry articles in a clean storage area until next use.

How to Wash Your Spraying Clothes

Never mix spray clothing with household laundry. Store and wash all clothing used for spraying separately from other clothing. Wash it after each use. **Remember to use chemical-resistant gloves to handle pesticide-contaminated clothing.**

- Presoak clothing before washing. Use one of three methods:
  - hose off garments outdoors
  - soak in separate tub or pail
  - use the prewash cycle in an automatic washer.
- Place the clothing directly into the washing machine. Wash only a few garments at a time. Do not wash with other family clothes.
- Use hot water, the highest water level and the longest cycle, with heavy-duty detergent. Wash as you would for heavily soiled clothing.
- Wash clothing again.
- After washing, hang outside (preferably in bright sunlight) until completely dry. Do not use the clothes dryer.

TABLE 1–2. Safety Supply Companies in Ontario Providing Protective Clothing and Equipment

3-M Canada Inc.	Occupational Health and Environmental Safety Box 5757 London, ON N6A 4T1	(519) 452-6165 1-800-364-3577 Fax: (519) 452-4660
Acklands Grainger	90 W. Beaver Creek Rd. Richmond Hill, ON L4B 1E7	(905) 731-5516 1-800-668-8989 Fax: (905) 731-2798
Aearo Canada	7115 Tomken Rd. Mississauga, ON L5S 1X7	(905) 795-0700 1-800-387-4304 Fax: (905) 564-5250
Dutch Industries "Protect-Air Cab Filter"	Huron Tractor, Box 1300 Exeter, ON N0M 1S3	(519) 235-1115 Fax: (519) 255-1939
HAMISCO	3392 Wonderland Rd. London, ON N6L 1A8	(519) 652-9800 1-800-668-9800 Fax: (519) 652-9661
Kappler Canada	Box 1687 20 Ryan Place Brantford, ON N3T 5V7	(519) 752-4369 1-800-387-9326 Fax: (519)752-2161
Levitt-Safety (Eastern) Limited	2872 Bristol Circle Oakville, ON L6H 5T5	(905) 829-3299 1-800-668-6153 Fax: (905) 829-2919
MSA Canada Inc.	148 Norfinch Dr. North York, ON M3N 1X8	(416) 667-9400 1-800-267-0672 Fax: (416) 663-5908
Mitt & Robe Co.	751 Norfolk St. N. Simcoe, ON N3Y 3R6	(519) 428-4050 1-877-893-6565 Fax: (519) 428-5142
Plant Products Co. Ltd.	314 Orenda Rd. Brampton, ON L6T 1G1	(905) 793-7000 1-800-387-2449 Fax: (905) 793-9632
Safety Express	4060B Sladeview Cres. Unit 2 Mississauga, ON L5L 5Y5	(905) 608-0111 1-800-465-3898 Fax: (905) 608-0091
The St. George Company (Suppliers of Kasco Helmets)	P.O. Box 430 20 Consolidated Dr. Paris, ON N3L 3T5	(519) 442-2046 1-800-461-4299 Fax: (519) 442-7191

- Clean the washing machine. Run the washing machine through one complete cycle using only detergent and hot water (without clothing).

Personal Hygiene

- Always wash your hands before you eat, drink or smoke.
- **When you are finished for the day, take a bath or shower as soon as possible.** The longer a pesticide remains on your skin, the greater the risk that it will be absorbed into your body.
- Wash your hair and under your fingernails. Shower with lots of soap and water.
- Always change into clean clothes.
- Wear clean work clothes every day. A small spill on the previous day's clothes may seem unimportant, but wearing the same clothing again without washing it prolongs the exposure and increases your risk.

Protect the Environment

Protect Contamination of Adjacent Land and Water Bodies

Do not allow pesticides to drift, run off or leach onto land or water bodies bordering treatment areas. Leave a suitable buffer zone between the treatment area and adjacent areas.

Protect Adjacent Land

No spray droplets should fall on adjacent properties, where treatments are not authorized.

Protect Water Sources

- Use an anti-backflow device to prevent back-siphoning when drawing water from wells, ponds, streams or other sources.
- Mix pesticide and load the sprayer away from any water supply, including wells, ponds or streams.
- Use buffer zones (untreated areas) when you apply pesticides to avoid contaminating surface water, wells, ponds and/or streams, especially those containing fish. Check the product label for specific buffer zone distances. See *Setback Distances for Water Bodies*, below.
- Do not allow equipment rinse water and excess pesticides to run into sewers or ditches with water in them. Rinse water should be put into spray tanks and applied to the treatment area. Otherwise, it must be disposed of as hazardous waste through a hazardous waste disposal company. For more information, see *Disposal of Pesticides and Empty Pesticide Containers*, p. 10.

Setback Distances for Water Bodies

It is an offence under the federal Fisheries Act to introduce any material into water that may be harmful to fish or fish habitat. To protect these waters, landscape applicators must determine a suitable setback distance between the area to be protected and the area where pesticide treatments are planned. The protected area includes the water body as well as adjacent riparian (riverbank) areas that contribute to fish food and habitat.

Reduce and Manage Pesticide Spray Drift

- Read the product label for information regarding buffer zones, water volumes and recommended nozzles.
- Use buffer zones around all watercourses and wells and neighbouring fields that contain sensitive crops. If the label does not state a specific buffer zone distance, leave an untreated area of natural vegetation.
- Select the recommended sprayer application rate (L/ha).
- Select the correct nozzle. Where practical, use air induction/venturi nozzles. These nozzles significantly reduce drift when compared to conventional nozzles.
- Select the correct nozzle-to-target distance.
- Spray only when winds are light to moderate (11 km/hr or less). If you notice drift is occurring because of the wind, **stop spraying** until the wind subsides. Do not apply pesticides if the wind is blowing towards susceptible crops or environmentally sensitive areas such as watercourses.
- Use spray plume protection where practical or available (hoods, shrouds, screens and air curtains).
- Use drift-reducing adjuvants in the spray tank as directed by the label.
- Utilize wick weeders, instead of spraying, when possible.
- Use non-volatile compounds.

For more information about spray drift, see the OMAF/Agriculture and Agri-Food Canada booklet *Best Management Practices — Pesticide Storage, Handling and Application* and the Ontario Pesticide Education Program (Ridgetown College) videos *How to Manage Spray Drift* and *Spray Drift Reduction Through Air Induction*.

Prevent Bee Poisoning

It is important to protect bees when you spray. Bumblebees, as well as other bees and insects, are important pollinators of crops.

If you choose to use insecticides for insect control, take these steps to prevent harming bees when you spray:

- Before you apply a pesticide in the greenhouse, close exits of hives 12–24 hours before spraying, remove hives from spray area. After pesticide application, vent greenhouse prior to re-introducing hives. This period before re-introduction should be in accordance to bumblebee supplier's recommendations.
- When there is a choice, choose the product formulation that is less hazardous to bumblebees. Dusts are more toxic than sprays. WP formulations are more toxic than EC formulations.

Most organophosphate and carbamate insecticides are highly toxic to bees. Examples of insecticides that are toxic to bees are listed below:

Trade name	Common name
Diazinon	diazinon
Intercept	imidacloprid
Pounce/Ambush	permethrin

Read each pesticide label for specific precautions regarding bees.

Disposal of Pesticides and Empty Pesticide Containers

Triple or Jet Rinse Your Empty Pesticide Containers

Unrinsed pesticide containers are not really "empty." They may still hold about 1% of the original amount of pesticide. Although this figure sounds low, it is still a hazard to humans, animals and the environment. To reduce the hazard, rinse each container three times as the spray tank is filling. Use either the manual triple rinse technique or a specially designed device for rinsing containers. Paper or cardboard containers are often strong enough to be rinsed. If it is possible, rinse these containers as well as plastic ones.

Triple Rinse

To triple rinse:

1. Fill the empty container at least 10% full of the diluting material (usually water).
2. Cap, then shake or roll the container so that the inside surfaces of the container are well rinsed.
3. Pour rinsings into the spray tank.
4. Repeat steps 1–3 twice more.

Remember to check the container after you have finished rinsing. Make sure that no pesticide has been left behind as a cake or paste on the bottom of the container.

Rinsing Devices

Rinsing devices use pressurized water to clean out the container. They are just as effective as triple rinsing but take less time. Follow the manufacturer's instructions.

How to Dispose of Empty, Triple-Rinsed Containers

Never reuse empty pesticide containers. They may be handy, but there is still some risk, even if the containers are triple rinsed. Empty, rinsed containers should never be given to anyone, especially children. Dispose of them promptly.

Regulation 914 of the Pesticides Act regulates how pesticide containers are to be disposed of in Ontario (Reg 914, s. 27).

Metal, Plastic or Glass Containers

An empty metal, plastic or glass container that has been used to hold a Schedule 1, 2, 3*, 5 or 6* (*non-domestic) pesticide shall be disposed of by:

- triple rinsing or jet rinsing using clean water, or another appropriate solvent

AND either

- taking it for recycling to a Pesticide Container Depot

OR

- taking it to a licensed waste disposal site.

Once containers are properly rinsed, puncture to make it impossible to use them again and to make sure the rinse water is out of the container.

It is often more convenient to store empty, rinsed containers until you have collected enough to make a trip to the recycling Pesticide Container Depot or the waste disposal site. If you store containers, keep them in a dry safe place, such as the storage area, until you can dispose of them properly.

Recycling

The Ontario Pesticide Container Recycling Program is available to growers and commercial exterminators.

Through this program, **clean, triple-rinsed, plastic/metal pesticide containers** (up to 23 L in size for plastic and 20 L in size for metal) can be returned to Pesticide Container Depots located throughout the province. To locate the Pesticide Container Recycling Depot closest to you, call the Ontario Pesticide Education Program at 1-800-652-8573.

Paper and Cardboard Containers

A paper or cardboard container that has been used to hold a Schedule 1, 2, 3*, 5 or 6* (*non-domestic) pesticide shall be disposed of by:

- triple rinsing or jet rinsing (if possible) using clean water

AND either

- burning (if allowed by municipal bylaws), in circumstances that persons and animals are kept out of any smoke produced and any smoke is directed away from buildings, highways, roads or outdoor areas frequented by the public

OR

- taking it to a licensed waste disposal site.

Paper or cardboard containers are often rigid enough to withstand rinsing. If possible, triple rinse these containers as you fill the tank. Then burn the containers in an isolated area on your farmland.

Be very careful around the smoke. It may contain toxic fumes from the burning pesticide. Be certain there is no chance a person or animal may breathe in this smoke. Make sure the smoke does not drift toward buildings, roads or any public outdoor areas.

These containers can also be taken to a local waste disposal site as for metal, plastic or glass containers. If you cannot dispose of them immediately, make sure containers are kept in a secure place such as the pesticide storage area.

Unwanted Pesticides

If you have pesticides you do not need or cannot use, be sure to dispose of them safely

- Contact the supplier. It is sometimes possible to return unused pesticide if it is still in its original container.
- If you cannot find any way to use the product as shown on the label, then the Ministry of the Environment requires that waste be disposed of by licensed waste haulers to a licensed waste disposal site. Look in the Yellow Pages of your telephone directory under "Liquid Waste Removal".
- Watch your local paper for "Municipal Hazardous Waste Collection Days" or contact your municipality. If your municipality has no waste collection days, encourage it to sponsor such an event. On these days, you can turn over surplus pesticide concentrates (maximum 25 L) for disposal.

Surplus Spray Mix

The best way to dispose of any excess spray mix is to find another section of the greenhouse that requires an application of this pesticide. Before spraying, check the label to make sure the pesticide is registered for use on that crop.

If you can't find another section to spray, then dilute the remaining spray mix by adding 10 parts of water for each 1 part of spray mix. This diluted solution can be safely applied to the treated area as long as you do not exceed the pesticide rate recommended on the label. Be sure to check the label for any restrictions about crop rotation, days to harvest or surplus spray mix disposal.

NEVER re-spray the treated greenhouse with undiluted spray mix. Spraying an area twice will double the recommended pesticide rate. This may cause illegal pesticide residues in the harvested crop or harmful residues in the soil that can cause crop damage.

Soluble Packaging Options

Choose soluble packages that dissolve in the spray tank to reduce container disposal. Water-soluble packaging is used for dry flowable and wettable powder formulations of pesticides and is available under names such as Clean Pak, Solupak and Toss-N-Go. In most cases, the water-soluble packaging material is PVA (poly vinyl acetate). This material dissolves completely when added to the water in the sprayer tank according to instructions.

Read all labels and instructions carefully. For more details, contact your vendor.

Keep soluble pouches dry until you add them to the spray tank.

- Do not handle pouches with wet hands or wet gloves.

- Do not remove pouches from the outer package until you are ready to add them.
- Always reseal the outer package to protect the remaining pouches from moisture.

Mixing Soluble Pouches

- Consult product labels for specific mixing instructions for each product.
- Fill the spray tank half full of water. With the agitator running, add the water-soluble pouches to the tank.
- Most pouches dissolve completely within 5 minutes, depending on the water temperature and the degree of agitation.
- As the tank continues to fill, add any other compatible pesticides.

Do not add:

- a pesticide that is incompatible with the PVA packaging material. The PVA material is not soluble with summer-type oils (e.g., Superior Oil).
- any material containing boron (e.g., Solubor), chelated micronutrients or water-soluble fertilizers. This combination is likely to cause a sticky, insoluble substance in the tank. If you apply boron, chelated micronutrients or water-soluble fertilizers, make sure that you completely empty and rinse the spray tank before you use any product packaged in PVA.

Storing Pesticides

Ontario's Pesticides Act and Regulation 914 give storage requirements for storage facilities. The storage requirements that you must follow depend on which schedules of pesticides that you store. See Table 1–3, *Pesticides Act Storage Requirements*, p. 12.

See also the OMAF Factsheet, *Pesticide Handling Facilities*, Order No. 94-037.

TABLE 1–3. Pesticides Act Storage Requirements

	Schedule		
	3, 4, 6	2	1, 5
No contact with food or drink	◆	◆	◆
Does not impair health/safety	◆	◆	◆
Clean & orderly manner	◆	◆	◆
Warning signs posted on storage buildings	◆	◆	◆
Warning signs posted on unattended vehicles	◆	◆	◆
Emergency telephone numbers posted	◆	◆	◆
Ventilated to outside		◆	◆
Limited access (locked)		◆	◆
No floor drain		◆	◆
Safety equipment available		◆	◆
Area used exclusively for pesticides			◆

Pesticide Spills

Protect yourself before you begin to clean up any spill. Clean up spills immediately.

In the case of minor spills:

- For liquids, cover the spill with a thick layer of absorbent material such as kitty litter, vermiculite or dry soil. Sweep or shovel the material into a waste drum.
- For powders and granulars, sweep or shovel the material into a waste drum.

In the case of a major spill:

- Remove any people or animals from the spill area.
- Stop the spill from spreading.
- Do not let the pesticide enter any watercourse.

If a pesticide spill causes, or is likely to cause, an adverse effect you must notify the Ministry of Environment Spills Action Centre at 1-800-268-6060 (24 hours a day, 7 days a week) and the municipality.

For information on preventing spills, see OMAF Factsheet, *Ways to Avoid Pesticide Spills*, Order No. 96-025. (See the page facing the table of contents for information on how to obtain factsheets.)

Types of Pesticide Application

Spraying

- Spraying is one of the most widely used and effective methods of applying pesticides.
- Clean and pressure-maintain nozzles to achieve a fine spray that will result in uniform coverage when the mixture is applied up to the point of runoff.
- Complete coverage is the objective; spray both the lower and upper leaf surfaces thoroughly.
- Calibrate spray equipment at start of season to ensure uniform application.

Fogs

- Fogs are produced by several kinds of machines.
- These machines all use heat from different sources to vaporize the pesticide.
- Fogging can be a very efficient method of pesticide application provided the operator follows the basic instructions.

Smokes

- Smokes are a very simple but effective means of pesticide application.
- There is no equipment involved; containers are simply placed on the path and lit.
- Do not use smokes in very old, loose greenhouses or during high winds.

Ultra-Low Volume

- There are several types of ultra-low volume (U.L.V.) applicators available.
- They atomize the pesticide solution into an extremely small particle size (7–20 microns).
- They distribute pesticide through the greenhouse by a forced-air fan system.

Electro-Static Sprayers

- Electro-static sprayers (E.S.S.) add an electrical charge to the fine spray particles.
- This enhances plant coverage by the pesticide and reduces drift.

Calibration

Calibration involves knowing the output of the spray application equipment, given the particular spray equipment being used and crop characteristics such as crop type, age, spacing, and production technique. Efficient and safe use of pesticides depends on proper application. Growers need to know exactly how much product to apply to avoid crop injury and excessive crop residues. To apply the correct amount of pesticides, growers must know their equipment and how they function. Calibration enables growers to predict the amount of pesticide that must be applied and the volume of water or carrier needed according to label instructions. For information on calibration, see the current OMAF Publication 75, *Guide to Weed Control*. Also see the calibration calculator on the OMAF web site.

Space Fumigants and Insecticide Smokes

- Learn about the health hazards and toxic properties of the pesticide being used. Consult the product label, Material Safety Data Sheets (MSDS) or manufacturer for this information.
- When using fumigants or insecticide smoke generators, wear protective clothing to prevent skin and inhalation exposure. During and after treatment, lock the building and post warning signs.
- Follow instructions on the product label regarding aeration of treated buildings, warehouses, grain storage bins or other areas before letting anyone enter.

Fumigants

- Always consult the product label.
- Agriculturalists using methyl bromide plus chloropicrin or aluminum phosphide to fumigate greenhouses must obtain a permit issued under Ontario's Pesticides Act.

- To apply for a permit, contact the local Pesticides Officer with the Ontario Ministry of the Environment.
- As a safety precaution, have someone else who is wearing personal protective equipment help with the fumigation.
- When handling methyl bromide, do not wear gloves because these will trap gas next to the skin. Wear a full-face respirator with organic vapour canister or positive-pressure breathing apparatus.
- When handling aluminum phosphide, use cotton gloves and wear a full face mask respirator with an acid-gas canister.
- For more information, obtain *Methyl Bromide Structure Fumigation Procedures* and *Aluminum Phosphide Structure Fumigation Procedures* from the Ontario Ministry of the Environment.

Wetting Agents

In the following discussion, the term "wetting agent" includes spreaders, stickers and surfactants, although these terms have slightly different technical meanings.

- Water will not always spread evenly over a surface. Its hydrophilic nature creates a high surface tension so that when placed on a leaf (hydrophobic) surface it forms large droplets that easily roll (with the pesticides) off the leaf and onto the ground.
- Reducing the water's surface tension by adding a wetting agent allows the water to make better contact with the leaves. Consequently, the pesticides spread more evenly over the leaf surface.
- Most pesticides are formulated with a wetting agent in them. However, in some cases (due to air or water temperature, water hardness, type of leaf surface, stage of plant growth and/or the type of formulation), the amount may not be adequate. Consult the label for specific recommendations.
- A simple method of determining if the amount of wetting agent present is sufficient is to spray a few plants at various times. Examine both the upper and lower surfaces of leaves at different growth stages for evidence of uniform wetting.
- If wetting is not uniform, add 125 mL of spreader per 1,000 L of spray. Then re-spray and re-examine. Continue until wetting is satisfactory.
- Wetting agents help the spray solution to wet powdery mildew mycelium, improving control. However, an excessive amount of wetting agent can cause plant damage, excessive foaming (which will cause pumping problems) or runoff (resulting in poor control).

Water for Irrigation and Pesticide Application

It is very important to neutralize alkaline water when using the water for irrigation and pesticide spray-tank mixtures.

Irrigation

- For crop irrigation, water should have a pH in the 6.0 range (acidic) in order to improve nutrient uptake. Many water sources in Ontario have a high pH (alkaline), which must be lowered.
- By testing the water, determine both the quantity and type of acid to add to achieve the desired pH level. Consult a greenhouse crop advisor.

Pesticide Spray-Tank Mixtures

- Because many pesticides breakdown in alkaline water, try to use pesticides diluted with alkaline water immediately.
- However, spraying immediately is not always possible. Note that any delay in applying spray mixtures will result in pesticide loss due to decomposition and, possibly, a corresponding decrease in control. To avoid this, neutralize alkaline water before adding any pesticides. Dissolve ammonium dihydrogen phosphate at the rate of 50 g/100 L water first, then add pesticides.
- The rate of decomposition depends on the pesticide, the concentration of pesticide in the tank (dilution factor) and the temperature of the water.
- The phosphate is not always necessary, but this practice provides insurance against pesticide loss. Phosphate costs substantially less than pesticides, and the added phosphate will be available as a foliar nutrient.

Preventing Groundwater Contamination

Groundwater is the source of water for wells and springs. If groundwater becomes contaminated with pesticides, it is difficult to clean. Preventing groundwater contamination is crucial. Some pesticides have the potential to leach through the soil to groundwater. Movement of pesticides into groundwater can make the water unfit for use. However, pesticides applied to the soil are subjected to physical, chemical and biological processes that affect their movement through the soil and their potential for groundwater contamination. Making the right pesticide choices for the situation can help minimize the threat of groundwater contamination.

Soil Characteristics

Soil texture plays a major role in pesticide performance and persistence. Soil organic matter can make a difference in pesticide activity. Therefore, it is important to select a pesticide based on soil type and organic matter content. Chemicals tend to leach more readily in coarse-textured soils with low organic matter content. In contrast, fine-textured soils with high organic matter are highly adsorptive and therefore have a low leaching potential.

Pesticide Characteristics

Some pesticides bind strongly (adsorb) to soils and therefore are not easily removed. Clay materials and organic matter favour strong adsorption. Use soil analysis information on organic matter content when selecting pesticides and application rates for your pest management program. Some pesticides are highly soluble in water, which can increase their leaching potential. Leaching of a pesticide can be minimized by pesticide dosage and by the timing and method of application. Choose the right pesticide for your situation.

The rate of degradation by natural processes is highly dependent on both the pesticide class (chemistry) and environmental factors. Sunlight, temperature, soil pH, microbial activity and other soil characteristics affect the breakdown of pesticides. Some pesticides break down slowly and therefore have a greater potential for leaching. On the other hand, short-lived pesticides may be degraded before any leaching occurs. Choosing a short-lived pesticide can minimize leaching potential. Microbial degradation occurs when fungi, bacteria and other soil microorganisms use pesticides as a food (energy) source. High organic matter, along with other properties such as optimum moisture, aeration, temperature and soil pH, can enhance microbial degradation. In addition, chemical degradation of pesticides can occur by reaction with water, oxygen and other chemicals. In general, pesticides that are highly water soluble, relatively persistent and not readily adsorbed by soil have the greatest potential for leaching.

Water Table

High water tables may be vulnerable to contamination by pesticides and fertilizers due to the relatively short distance between the soil surface and groundwater. There is potential for groundwater contamination in areas with coarse-textured soils and high water tables. Specific application information for each pesticide is contained in the pesticide label. Careful adherence to application and disposal directions, combined with proper equipment calibration, provide the best method of preventing groundwater contamination.

2. Factors Affecting Greenhouse Production

The Ontario greenhouse vegetable industry has undergone many changes this past decade. Responding to improved production practices, efficiencies, quality and expanding markets, the industry has more than doubled in just eight years.

Since 1997 double polyethylene-covered greenhouses have replaced glass as the choice material of construction. They are less expensive to build, save 10%–20% in heating costs, reduce electrical costs for fan cooling in the summer and have a similar production/unit area as glass. Glass, however, maintains its popularity. Of the 10% expansion of greenhouse production area in 2004, 50% of that construction consisted of modern glass (Venlo style) houses.

Other changes that have helped the industry expand includes:

- increased gutter height, which improves the greenhouse environment
- installing environment-control computers in all new construction and retrofitting older operations
- the dramatic increase of hydroponic/soilless culture, where most operators now grow in rockwool or coir (Cocos peat), with less than 5% grown in NFT, peat or soil
- increased use of raised trough systems for the growing media
- increased use of hot water heating systems with flue gas CO_2 recovery and hot water storage tanks.

Integrated Pest Management (IPM) is practised by Ontario greenhouse vegetable operators. Manipulating the greenhouse environment, using scouting programs and biological control agents are instrumental in maintaining a high quality product.

Marketing is the key to a flourishing industry. High quality, flavour and service are important factors for a successful market strategy, and the Ontario Greenhouse Vegetable Growers (OGVG), formerly the Ontario Greenhouse Vegetable Producers' Marketing Board, plays a key role. Established in 1967, the OGVG has been instrumental in marketing and promoting greenhouse grown tomatoes and cucumbers.

Introduction

Maximizing production and quality in a greenhouse operation requires proper management and control of plant growth. Factors such as light, temperature, water, nutrition, insect and disease pressures and the crop and cultivars grown are key components affecting growth and yield. Some of these factors are easily controlled, while for others control is either uneconomical or impossible.

For example, prevailing low light conditions in winter are not normally adjusted, except where artificial light is used to supplement day length at seedling or plant raising stages. However, during the summer when light levels are high, shade curtains or whitewashing the greenhouse exterior reduce light transmission to the crop.

Control can be imposed on the plant by manipulating one or all of these factors.

The major objective of a greenhouse is to provide an environment for optimum plant growth. Light, carbon dioxide, water, nutrients and temperature are all required for plant growth. Light is often considered the limiting factor; therefore greenhouses are built to maximize light penetration to maintain growth during the darker months. This chapter discusses some of the growth factors related to greenhouse production.

Vegetative or Generative Plants

Adjustments to light, temperature, water and nutrient regimes ensure that a certain form or look of plant is obtained. For example, a *vegetative* plant is one that produces more leaves than flowers and fruit. In this case the plant:

- has large, thick, dark green leaves and a thick stem with a light green tinge at the growing point
- has large, rough flowers on weak flower stems and trusses
- fruit size is small relative to plant size
- may have extensive root growth.

On the other hand a *generative* plant has:

- smaller leaves and a thin stem with a purple tinge at the growing point
- smaller, numerous flowers prominently displayed
- large fruit compared to the size of the plant
- possibly poor fruit quality because of overexposure to the sun.

A balance between these two types of plants is optimal.

At certain times of the year, the plant must be guided towards the vegetative phase and then shifted towards the generative phase by the grower. Early in the planting cycle plants tend to be vegetative. Control must be implemented early to obtain a generative plant that will provide fruit at the desired time. However, plants may become too generative and adjustments to the cropping strategies are required to encourage a more vegetative growth.

A plant grown at low temperature and high humidity during early winter when light levels are traditionally low, tends — if amply supplied with water and nutrition — to be vegetative, (i.e. thick stemmed, large leaves, short, stocky plant, with large flowers and small fruit). By raising the temperature (within reason), decreasing the humidity, water and nutrition, a more controlled plant may be obtained.

Further changes may be made to the way the plant grows by adjusting the day-night temperatures. During sunshine hours, a higher temperature allows the plants to manufacture sugars and grow rapidly. At night, lower temperatures allow the sugars manufactured during the day to be translocated or stored in the stem and root growing points, the fruit and the leaves — resulting in thicker, heavier plants. Adjusting the temperature and determining when to make these adjustments are tools continuously used in the greenhouse to obtain a well-balanced, highly productive crop.

Effect of Temperature

Plant temperature influences several important processes, all of which affect growth.

Effect on Photosynthesis and Respiration

Photosynthesis is the process where plants convert carbon dioxide (CO_2) and water (H_2O) into carbohydrates and oxygen. This process requires light energy, which means photosynthesis can only take place when visible light is available to the plant. In a way, the plant is storing energy in the form of carbohydrates.

Respiration is the process that accomplishes the opposite effect of photosynthesis; carbohydrates are

converted back to carbon dioxide and water, releasing energy. This energy is then used to help processes such as root, leaf and bud initiation, and development. Respiration does not depend on light, taking place 24 hours a day. The rate of respiration is influenced by temperature.

The net effect of the two processes can be expressed as an accumulation of dry matter or growth. The optimum temperature to obtain the maximum increase in dry matter depends on the light intensity. The higher the light intensity, the higher the optimum temperature. For most greenhouse crops, this optimum is between 12°C–16°C during low light conditions and 15°C–25°C when light intensity is high.

Rate of Development of Leaves, Flowers and Roots

These processes require energy and coincide with the rate of respiration. The 24-hr average temperature is important for these activities. For each degree Celsius increase between 10°C–30°C, there is a 10% increase in leaf and flower initiation. Thus, the 24-hr average temperature determines the rate of crop development. Under low light conditions, the 24-hr average temperature is lowered and under high light conditions, the average temperature is raised.

The degree of adjustment is determined by observing the morphological characteristics of the plant. At a low 24-hr average temperature, the plant tends to have shorter internodes, thicker stems and leaves, and large flowers. At a high 24-hr average temperature, the plant tends to have longer internodes, thinner stems and leaves, and small, spindly flowers. Too high or too low a 24-hr average temperature is detrimental to the crop. Higher temperatures weaken the plant and flowers, causing yield reduction, while low temperatures delay harvest or damage flowers resulting in malformed fruits.

Shape and Development

Temperature influences size and shape of leaves. For example, cucumbers and lettuce have short, wide leaves when temperature at initiation is low, while at high temperatures the leaves are long and narrow.

The day-night temperature differential affects the plant's shape. A small or even day-night temperature differential results in more vegetative plants with short internodes and thicker larger leaves; a large day-night temperature differential results in more generative plants with longer internodes and thinner, smaller leaves. Use a more even day-night temperature regime in early development (to establish a plant); apply a differential after flowering and fruit setting stages.

Effect on Humidity

Temperature has a direct influence on humidity. When temperature increases, relative humidity (RH) decreases. The reverse is also true. Relative humidity has a direct affect on the transpiration rate and, therefore, on the water status of the plant. In general, plants grown at high RH have larger leaves and longer stems than those grown at a lower RH.

The optimum temperature for each crop influences the above factors and depends on light conditions, the stage of growth and season. The temperature at which a crop is grown can control the rate of crop growth, its vigour, the shape or morphology of the plants, fruit size and ultimately, yield. Generally, the optimum temperature for lettuce is 17°C–18°C; tomatoes 19°C; peppers 19°C and cucumbers 21°C. Several temperature schemes have proven beneficial.

Figure 2–1, *Temperature Profile of Greenhouse Crops — Sunny Day*, p. 20 and Figure 2–2, *Temperature Profile of Greenhouse Crops — Cloudy Day*, p. 20 are examples of temperature manipulations used to develop the ideal plant with good form and a high quality production. This scheme is attempting to maintain a 24-hr average temperature, but allowing for a higher afternoon temperature to increase speed followed by a lower early night temperature to create a strong head, root and fruit base.

Temperature Control

Heating

Temperature requirements of the major greenhouse vegetable crops (i.e., tomatoes, cucumbers, peppers, lettuce) vary significantly. The heating requirement for a greenhouse range can be calculated on an hourly and yearly basis. Inside and outside temperatures, the type of glazing material and the surface area of the greenhouse must be known for these calculations. Greenhouse heating companies will design systems suitable for local conditions.

FIGURE 2–1. Temperature Profile for Greenhouse Crops — Sunny

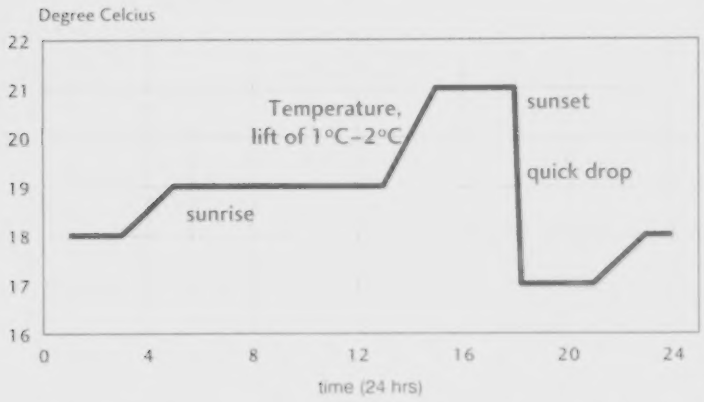
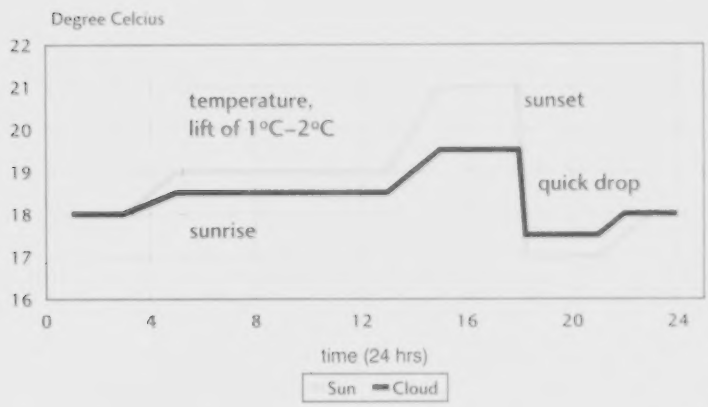


FIGURE 2–2. Temperature Profile for Greenhouse Crops — Cloudy



The standard recommendation for a 35°C temperature differential is 350 watts per metre squared (W/m^2) for a glass greenhouse and 270 W/m^2 for a double polyethylene greenhouse. In southwestern Ontario, a general rule of thumb is 100 hp boiler for 0.4 ha (1 acre) of greenhouse. If thermal curtains are installed, these figures can be reduced by 25%–35%. Although some crops require less heat (e.g., lettuce) than others, heat requirements for a high temperature crop should be accommodated in the design of the heating system so growers can easily switch to other crops at a later date.

The most common heating system in Ontario greenhouses is a central heating system. The source of energy is primarily natural gas, with some growers using waste wood. Bunker oil and #2 oil are used as a standby, although a few growers use it as their main source of energy. Several growers use propane, especially those not close to natural gas supply lines.

Heat is provided in the form of steam or hot water from a centrally-located boiler through a system of heating pipes. The main advantage of such a system is the pipes can be located in areas where the greatest heat losses occur (i.e., perimeter), or where it is most efficient (i.e., within the crop — about 30–60 cm above the ground). Hot water systems have the added benefit of being able to regulate the temperature of the water within the pipes. Typically, heating pipes are located within the crop to help maintain good air movement around the plants. Crop zone heating pipes used as pipe rail systems for battery/electric powered carts is an additional advantage. This makes the work less strenuous for the employees.

Gas fired unit heaters are an alternative to a central heating system. Although economical to install, major drawbacks are poor temperature distribution, greater temperature fluctuations, lower seasonal combustion efficiency and the possibility that gases from the flue may enter the greenhouse. Some growers have attached duct work to the units and direct the warm air via large poly tubes distributed between the plant rows to heat the greenhouse. This greatly improves heat distribution within the greenhouse. As well, they provide a direct source of outside air to the fire box, minimizing the possibility of improper burn.

Cooling

Although greenhouses require a great deal of heat to maintain temperatures during the winter, it is also necessary to reduce temperatures during the warmer months. Cooling is normally done by exchanging greenhouse air with outside air. One air exchange per minute is required for high temperature, summer conditions. Two systems presently used are natural ventilation (peak ventilation for glass and acrylic houses, gutter ventilation for double polyethylene greenhouses) and forced air ventilation (fan cooled greenhouses). With forced air ventilation, additional summer cooling can be achieved by also installing a fan and pad system. Some growers are using high pressure fogging systems for both spring and summer cooling, and for humidity control in the winter and spring.

Temperature Sensing and Control

Using computers for greenhouse temperature and environmental control is now standard. With a computer, temperature can be automatically controlled depending on the time of day, intensity of sunlight, relative humidity or many other factors. In addition to a static temperature set point, the computer allows for the ramping of temperatures from night to day. Ramping (controlled temperature increase or decrease) provides more accurate optimum temperatures for plant growth. This allows for a temperature profile specific to a selected cultivar or style of growing.

Computers require an extensive initial investment and may be economically viable only for large greenhouse operations. However, the improved temperature, RH control and disease management make computers essential for all greenhouse sizes.

Traditionally, growers used mechanical temperature sensors. However, electronic sensors (thermistors), in conjunction with analogue or digital controllers, are now available. The sensor measures the temperature in the immediate area and must be placed near the growing point of the plant canopy. As the plant grows, the sensor is raised to monitor the temperature at the growing point.

Since temperatures often vary in different parts of the house, the sensor is placed in an aspirated box. The aspirator will draw greenhouse air across the thermometer and give it a more representative sample of temperature.

Light

Light is the primary productive factor in plant growth. The process of photosynthesis, where a green plant takes carbon dioxide from the air and water from the root zone to manufacture food, is powered by the energy absorbed from light.

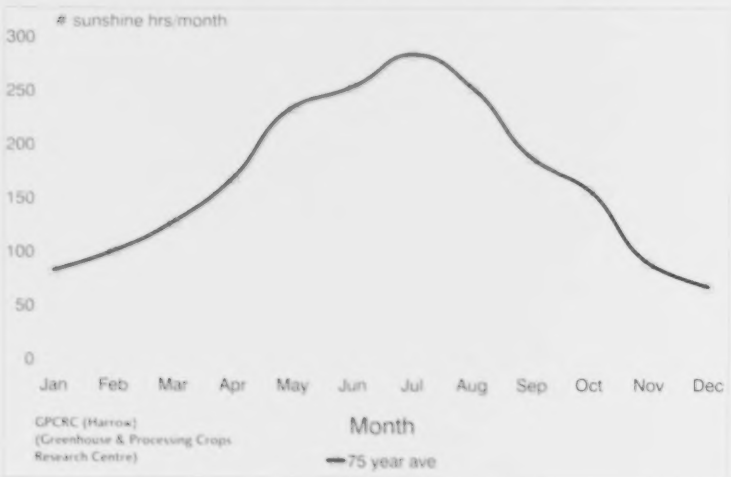
$$6CO_2 + 6H_2O \xrightarrow{\text{Light}} C_6H_{12}O_6\text{(sugars)} + 6O_2$$

In greenhouse production, light is the fundamental factor in plant growth over which growers have the least control.

Artificial light supports photosynthesis, but energy costs make it uneconomical to grow most vegetable crops this way. However, using supplemental light is common in the growing of seedlings and transplants before planting out. In general, supplemental light at 20 W/m^2 for the desired photoperiod is adequate and economical. It will provide stronger, stockier plants in a shorter period of time during the low light, short days of December and January.

Normal sunlight patterns are presented in Figure 2–3, *Sunshine Hours*, Figure 2–4, *Sunshine Radiation*, p. 22 and Figure 2–5, *Global Radiation*, p. 22. With little light energy available for growth in mid-winter relative to the summer, it often takes twice as long to get the same amount of growth in January as in May. This must be considered when scheduling the production of greenhouse vegetable crops. Greenhouse management practices should be adjusted to suit prevailing light conditions. Both seasonal and daily temperature and nutrient adjustments must be made in relation to the expected light levels.

FIGURE 2–3. Sunshine Hours —75 year average



Interaction Between Light Intensity and Plant Leaf

There is an interaction between leaf size and light intensity. This is particularly true for young, expanding leaves during periods of low light intensity. Research shows that a reduced light intensity is compensated, to some degree, by a larger leaf surface area without affecting the photosynthetic rate per unit surface area of these leaves. Larger leaves also mean more light will be intercepted, improving the overall conversion efficiency of the plant.

FIGURE 2–4. Sunshine Radiation Weekly Average (MJ/m²/day)

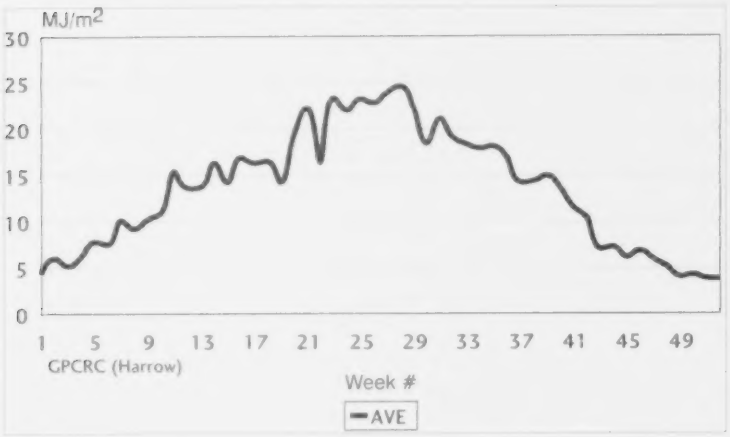
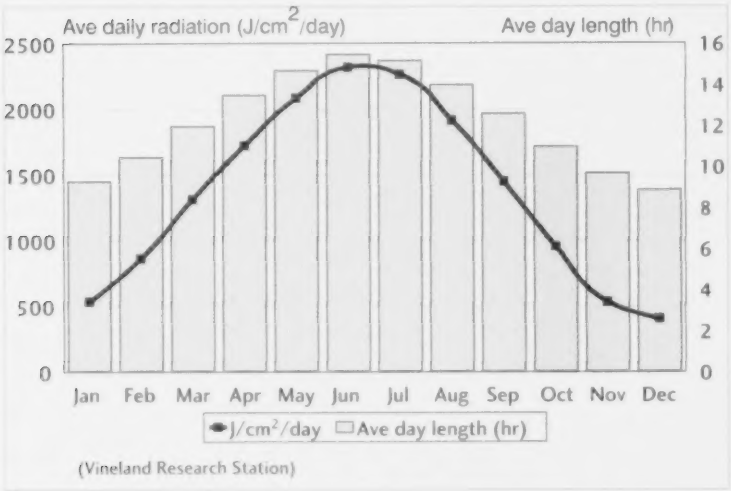


FIGURE 2–5. Global Radiation (10-year average)



These large leaves are usually thin cuticled and more prone to damage when manipulated during normal cultural practices. Leaves grown under high light intensity usually have a thicker cuticle.

Plants adjust to lower light levels. Anatomically, in leaves produced under high light conditions, the light-capturing chloroplasts are arranged parallel to the sun radiation; in leaves formed under low light conditions the chloroplasts are aligned perpendicular to the sun radiation to capture more light energy. However, the degree of adjustment depends on the age of the plant or leaves and the length of time of acclimatization. This explains, in part, why spring grown plants are bigger than fall grown plants, even though the same amount of light may be received by the plants.

Light Transmission

Glazing material greatly affects the amount of light received inside the greenhouse. Glass has been the traditional glazing for vegetable greenhouses. However, for the past 10 years double poly greenhouse structures have become increasingly popular. The reasons for this change are energy conservation and low capital construction costs, without loss of productivity (Figure 2–6, *Comparison of Light Transmission between Glass and Double Polyethylene Covered Greenhouses*, p. 23).

Current roof designs and increased gutter height of greenhouses provide for improved light transmission, a better environment and improved growing conditions.

Many conflicting reports have been published on light transmission of different materials. Different measuring techniques usually account for these discrepancies. Light transmission is defined as the ratio of light passed through a material and the original amount of light striking the outer surface of any object when that light is directed perpendicular to the material. In general, only 60%–75% of light striking the outer surface actually reaches the plant.

The most useful light for photosynthesis is between 400 and 700 nM wavelength, known as photosynthetically active radiation (PAR).

Light intensity is often expressed in radiation terms as Watts per metre squared (W/m^2) or Joules per metre squared (J/m^2) or photometrically in lux or foot candles. Table 2–1, *Conversion Table for Light*, p. 23, shows the conversion factors used to change the light reading expressions. This allows a comparison of light readings recorded by different equipment as well as those by the various environment control computers.

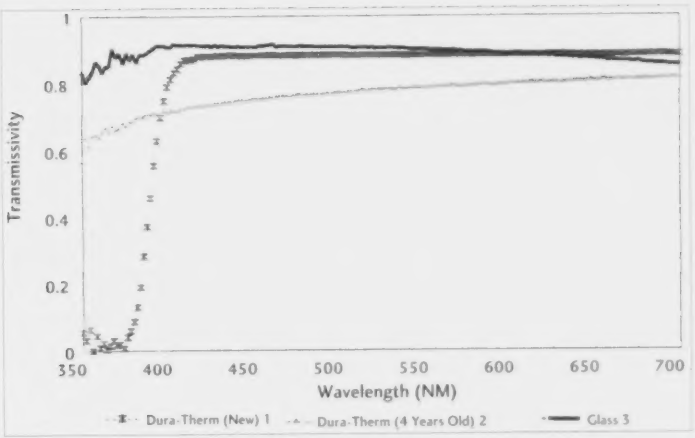
Two major factors that determine the light transmission of glazing are the refractive index and the amount of light absorbed by the material itself. Theoretical calculations show that for glass about 4% of

TABLE 2–1. Conversion Table for Light

Light Source	W/m^2 to $umol/m^2/sec$	$umol/m^2/sec$ to W/m^2	lux to $umol/m^2/sec$	$umol/m^2/sec$ to lux	lux to W/m^2
sunlight	4.57	0.22	0.02	54.00	0.004
high pressure sodium (SON/T)	4.98	0.20	0.01	82.00	0.002
incandescent	5.00	0.20	0.02	50.00	0.004
high pressure mercury	4.52	0.22	0.01	84.00	0.003
metal halide	4.59	0.22	0.01	71.00	0.003

W/m^2 – watts/m^2
umol/ m^2/sec – micromols/m^2/sec

FIGURE 2–6. Comparison of Light Transmission Between Glass and Double Polyethylene



the light is reflected at each glazing/air interface. This means that the maximum light transmission for a single layer of material is about 92%. This explains why light transmission through a double layer of glazing material is considerably less than through a single layer of the same material with a total thickness equal to the double layer.

The maximum theoretical transmission through a double layer material such as glass is 85%, indicating that the major loss of light is through reflection, not absorption. This also accounts for the relatively small difference in light transmission between 100 and 150 micron polyethylene films.

Development in the polyethylene film industry has seen changes in the light transmission properties of the newer plastics, improving light reception and quality at the plant level. Adjustment of UV transmission to decrease disease incidences and allow bumble bees to function well have been made to the poly films presently used.

Relative Humidity (RH)

Relative humidity is the ratio of the actual amount of water vapour present in a given amount of air (i.e. absolute humidity), to the maximum amount of water vapour that can be held within that volume of air at a given temperature. RH is expressed as a percentage and varies between 40% and 100% in most greenhouses.

The actual amount of water in a given volume of air for various relative humidities is given in Table 2–2, *Water Content of Air at 18°C for Various Humidities*, p. 24. The amount of water vapour which air can contain is strongly correlated with temperature, as illustrated in Table 2–3, *Effect of Temperature on the Saturated Water Content of Air*, p. 24, almost doubling for every 10°C increase in temperature.

Relative humidity is a common term used to describe moisture in the air. However, as shown in Table 2–2 and Table 2–3 the water content of the air varies at different temperatures.

Although RH is 70% at the three temperatures indicated, the actual water present is quite different. The difference between maximum water and actual water present provides a vapour deficit that gives a better knowledge about the drying capacity of the air. For example, at 20°C and 70% RH, the air can hold only 6.4 g/m^3 water. But at 30°C and 70% RH, it can hold 10.2 g/m^3 water. This difference affects transpiration (Table 2–4, *Vapour Pressure Relations*, p. 24).

In this example, the lower vapour deficit at 20°C means the transpirational pull is not as high as at the higher vapour deficit of 30°C. Within the leaf, the air

TABLE 2–2. Water Content of Air at 18°C for Various Humidities

Relative Humidity (%)	Water Content (g/m^3)
100	15.7
80	12.6
60	9.4
30	4.7

TABLE 2–3. Effect of Temperature on the Saturated Water Content of Air

Temperature °C	Water Content (g/m^3)
–20	1.1
–10	2.4
0	4.9
10	9.5
20	17.8
30	31.8

TABLE 2–4. Vapour Pressure Relations

Temp.	RH	Max. water	Actual water	Vapour Deficit (g/m^3)
20	70	17.6	12.2	5.4
25	70	23.6	16.4	7.2
30	70	31.7	21.9	10.2

is saturated or is at 100% RH. Air outside the leaf is not fully saturated, that is, below 100% RH. The difference between these values — water vapour in the leaf and water vapour outside the leaf — determines the transpirational rate.

Water movement from the leaf into the atmosphere occurs through open stomata (controlled by biological factors such as light, temperature, stature of the plant).

Vapour Deficit or Vapour Pressure Deficit

Vapour deficit or vapour pressure deficit (VPD) is a commonly used mathematical term determined by measuring the wet bulb and dry bulb temperatures used to determine the optimal conditions for transpiration. Water vapour in the air exerts pressure and is indicated in millibars (mbar) or kiloPascals (kPa) of pressure. Humidity deficit also indicates the difference between the water vapour present in the plant and that present outside. Table 2–5, *VPD Relationship to Temperature and RH*, p. 25, shows the VPD values from various temperature and RH values. Optimal VPD is 0.4–0.8 kPa (4–8 mbar) and is indicated by the clear values on the chart. Optimal transpiration rate and nutrient uptake, coupled with adequate sugars at these VPD values, result in healthy, vigorous, high yielding plants.

Plant vigour and growth rate can be altered by adjusting the VPD. Maintaining too low a VPD results in low transpiration, thicker larger leaves, thick stems, weaker root systems and plants more prone to disease infestations. Too high a VPD results in a high transpiration rate, thinner, smaller leaves, thinner stems and a stronger root system. Extreme VPD values or rapid fluctuations in VPD (low or high) are detrimental to plant growth, fruit quality and productivity.

The VPD can be adjusted in the greenhouse by altering heating temperatures, venting rates and air movement. Water availability to the crop, misting or fogging systems also alter the VPD.

If the greenhouse air is heated or cooled without changing the actual amount of moisture present, the relative humidity will decrease or increase respectively. Where different day and night temperature regimes are established, these relative humidity changes occur regularly. For instance, many growers increase the temperature at sunrise by about 3°C, lowering the relative humidity by 12%–18% and inducing an increased transpiration rate. In the evening, the drop in temperature increases the relative humidity, requiring some ventilation to prevent disease development.

A rule of thumb for most greenhouse conditions is that for each degree Celsius increase in temperature, the relative humidity drops about 4%–6%. The inverse also holds true.

When moist air reaches the saturation point, condensation occurs on the cooler surfaces in the greenhouse. During the day, leaves are usually warmer than the surrounding air, but due to radiant heat loss at night, the leaf temperature may drop 1°C or 2°C below ambient air temperature. If the greenhouse RH is near 95%, condensation may take place on leaf surfaces. Prolonged periods of high relative humidity and free water encourage bacterial diseases and the germination of many fungal spores, such as Botrytis or powdery mildew.

Relative humidity also affects pollen transfer. For tomatoes, RH must be between 70%– 75% for pollination. This permits the proper release of pollen

TABLE 2–5. VPD Relationship to Temperature and RH (mbars)

TEMP °C	RH									
	50	55	60	65	70	75	80	85	90	95
15.0	8.5	7.7	6.8	6.0	5.1	4.3	3.4	2.6	1.7	0.9
16.0	9.1	8.2	7.3	6.4	5.5	4.6	3.6	2.7	1.8	0.9
17.0	9.7	8.7	7.8	6.8	5.8	7.5	3.9	2.9	1.9	1.0
18.0	10.3	9.3	8.3	7.2	6.2	5.2	4.1	3.1	2.1	1.0
19.0	11.0	9.9	8.8	7.7	6.6	5.5	4.4	3.3	2.2	1.1
20.0	11.7	10.5	9.4	8.2	7.0	5.9	4.7	3.5	2.3	1.2
21.0	12.4	11.9	9.9	8.7	7.5	6.2	5.0	3.7	2.5	1.2
22.0	13.2	11.9	10.6	9.3	7.9	6.6	5.3	4.0	2.6	1.3
23.0	14.1	12.6	11.2	9.8	8.4	7.0	5.6	4.2	2.8	1.4
24.0	14.9	13.4	11.9	10.4	9.0	7.5	6.0	4.5	3.0	1.5
25.0	15.8	14.3	12.7	11.1	9.5	7.9	6.3	4.8	3.2	1.6
26.0	16.8	15.1	13.4	11.8	10.1	8.4	6.7	5.0	3.4	1.7
27.0				12.5	10.7	8.9	7.1	5.4	3.6	1.8
28.0				13.2	11.3	9.5	7.6	5.7	3.8	1.9
29.0					12.0	10.0	8.0	6.0	4.0	2.0
30.0					12.7	10.6	8.5	6.4	4.2	2.1

Note: The clear area is the optimum range for most greenhouse crops
1 mbar = 0.1 kPa
0.1 kPa = 0.7 g/m3 = 3% RH

from the anthers onto the stigma. After pollination, a higher RH helps the pollen to germinate, improving fertilization and increasing fruit size.

An extremely low RH may occur when large amounts of dry air enter the greenhouse on a bright, sunny day during the early part of the year. The cooling cycle must be monitored closely during this period. Too much ventilation reduces RH too rapidly and may cause burning of tender foliage or curling of young cucumber fruit, decreasing fruit quality and yield.

Misting or fogging systems that maintain RH can be installed to prevent damage to specific crops. During the summer, when forced ventilation is needed, a high daytime RH is often not a problem, unless a fan and pad system has been installed for cooling. However, at night, ventilation and/or heating are often required to prevent excessively high RH and condensation on the foliage.

Carbon Dioxide (CO_2)

The ambient CO_2 level of outside air is about 340 ppm (ppm = parts per million) on a volume basis. During photosynthesis, plants absorb CO_2 from the air and combine it with water (H_2O) to produce carbohydrates necessary for plant growth. This process is energy driven and can only occur when there is sufficient solar radiation (light). Consequently, the CO_2 level in an air-tight greenhouse (if not adequately vented) can drop well below the ambient level, especially during sunny periods. Low CO_2 levels reduce photosynthetic activity, lowering plant growth and fruit yield. Significant reductions in CO_2 concentration in the greenhouse have been observed during periods of bright sunlight, even with summertime ventilation (as low as 200 ppm). Supplemental CO_2 during ventilation may be economical, but it must be considered on its own merit for each operation.

Research shows that plant growth is improved by 15%–20% in greenhouses when CO_2 levels are increased to 800–1,300 ppm during the day. The optimum level of supplementation depends on the crop and the air movement within the greenhouse. In general, the optimum CO_2 level with good air circulation is around 1,000 ppm on sunny days and 400 ppm on cloudy days, or when vents are opened more than 10%. In Ontario, most greenhouse growers with year-round operations introduce supplemental CO_2 into their

greenhouses, monitored with CO_2 controllers to maintain set points.

Methods to Increase CO_2

The most common method of increasing CO_2 levels is through fuel combustion such as natural gas, propane or low sulphur kerosene. These fuels are burned in special units positioned at appropriate locations in the greenhouse to improve distribution. Flue gas CO_2 from the heating plant/boiler system is an alternative source for supplementing CO_2. Heat available from flue gas CO_2 generation is stored as hot water in large buffer tanks for use at night when heat is required. Liquid CO_2 has become popular and with increased use, more economical.

Interest in supplementing CO_2 during the summer when vents are fully opened is increasing. Maintaining 400 ppm CO_2 levels when vents are fully opened improves fruit size, quality and colour. Liquid CO_2 and flue gas CO_2 lend themselves well for summer CO_2 supplementation. This potential increase in yield must be balanced with increased cost — and the possibility of poor returns due to market conditions.

The rate of supplemental CO_2 depends on the infiltration rate of outside air into the greenhouse. Burner capacity, or the rate of supplemental liquid CO_2 for different types of greenhouses, is listed in OMAF Factsheet, *Carbon Dioxide in Greenhouses*, Order No. 94-055. As a rule, a CO_2 supplementation rate of 45–65 kg/ha/hr maintains 1,000 ppm in a closed greenhouse, or 350– 400 ppm in a vented greenhouse. This factsheet also deals with CO_2 distribution, cost and dangers of incomplete combustion.

Energy Conservation

The judicious use of energy conservation technology is recommended for commercial greenhouses. However, the impact of this technology on crop production must be considered.

Energy conservation techniques, such as double poly greenhouses and/or double walled, SDP/acrylic side walls, are common in Ontario. Management and cultural practices have changed to compensate for the lower light transmission and the lower rate of air exchange per hour without any detrimental effect on crop production. (Natural air exchange in a glass house is 0.75–1.5 exchanges/hr, while double poly greenhouses have 0.2– 1.0 exchanges/hr.) Increased energy costs in the 1970s resulted in energy conservation techniques and lower greenhouse temperature settings. But most Ontario greenhouse operators found that maintaining a lower 24-hr average temperature to conserve energy is not cost effective. A better return is achieved by optimizing the conditions for maximum economic yield.

While shade/energy curtains are not common in Ontario, some newer greenhouses are now using them. Modern glass greenhouses use energy curtains routinely.

Water

Water supply and quality for greenhouse crop production is very important. Select a site with ample supply of high quality water. Most greenhouse vegetable operations in southwestern Ontario use municipal water from the Great Lakes. Other operations rely on well water or rainfall collected in ponds. Rivers or streams are not recommended as the only source of water as there is a high risk of contaminants causing damage to the greenhouse crop.

In most areas, municipal water is of adequate quality, with soluble salts of less than 0.750 milliSiemens per centimetre (mS/cm)[1]. Conduct water tests if using well water, which may be of very poor quality and unsuitable for continuous irrigation. Contact OMAF's greenhouse vegetable specialist for advice.

Generally, water quality for greenhouse use may be divided into 3 classes (Table 2–6, *Classification of Water Quality*).

TABLE 2–6. Classification of Water Quality

Class	Electrical Conductivity (mS/cm)	Sodium (ppm)	Chloride (ppm)	Sulphate (ppm)
1	0.5	30	50	100
2	0.5–1	30–60	50–100	100–200
3	1.0–1.5	60–90	100–150	200–300

- Class 1 water is satisfactory for all purposes.
- Class 2 water may be used in substrate and soil culture where leaching can be done. However, it is unsuitable for NFT (nutrient film technique)

1. 1 mS/cm = 1 mmhos/cm or 1000 µS/cm = 1,000 µmhos/cm.

crops or where recirculation of nutrient solutions is planned.

- Class 3 water is the least desirable and should not be used for salt-sensitive crops.

The quality of irrigation water is more important in hydroponic/soilless culture than in soil. Always consider water quality when establishing a fertilization program. For example, if the water contains large amounts of calcium or magnesium, reduce the rates of calcium nitrate and magnesium sulphate accordingly. Any nitrogen lost because of these adjustments can be made up by increasing the amount of another nitrogen-containing fertilizer. Note that certain trace elements such as iron, zinc and manganese can be high in some water supplies.

Use water with sodium and chloride levels below 50 ppm and 70 ppm respectively to create feed schedules for greenhouse vegetable crops. Avoid water containing higher levels (e.g., 100 ppm sodium or 140 ppm chloride). Find alternative water sources or use a water purification system such as reverse osmosis. Tomato crops may be grown in a nutrient solution containing 100 ppm chloride without too much difficulty. However, it is best to select a water source that is low in these two elements.

When using rain water, the usually low level of bicarbonate is raised by adding potassium bicarbonate to the water (not to the stock solutions). When the bicarbonate in the water supply is higher than 60 ppm, add phosphoric and/or nitric acids to adjust to the proper pH.

In areas where no municipal or lake water source is available, consider a cistern or a pond for collection and storage of rain water. Remember more water is used in year-round crop production than the yearly rainfall collected from the roof of a greenhouse range. This means an additional water source is required. To meet the needs of a fully-grown crop, the irrigation system must be able to deliver at least 8 L/m^2/day. Some fully-grown greenhouse crops (e.g., cucumbers) may require up to 5 L of water/plant/day during the sunny, summer months (Figure 2–7, *Water Application in Greenhouse Vegetables*).

Nutrient Solution Recycling

Nutrient solution recycling reduces the water use in a greenhouse operation by 25%–30% and decreases the use of fertilizer 30%–40%. As well, with the enactment of the Nutrient Management Act, 2002 greenhouse vegetable operations could, in the near future, be required to account for their inputs and outputs. Nutrient solution recycling is a good technique to help growers comply with any new regulation. The greatest fear when implementing nutrient solution recycling is that of disease transfer via the recirculating nutrient solution.

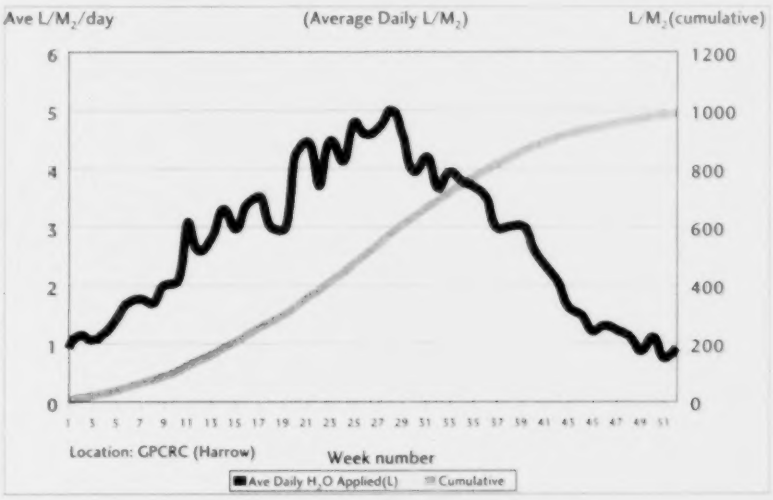
Nutrient Solution Disinfection

There are several systems available for a grower to use. All systems disinfect the nutrient solution (i.e. will remove most plant pathogens). Factors determining which system to select include:

- available space (to place the equipment)
- the desire for a completely disinfected nutrient solution or the maintenance of a biological nutrient solution
- initial investment and running cost
- ease of maintenance.

A basic set up (Figure 2–8. *Nutrient Solution Recycling Layout*, p. 29) requires a collection system that moves the solution to a central collection point, passes through a treatment system and then stores before blending with fresh water and reapplied to the

FIGURE 2–7. Water Application — Greenhouse Vegetables



crop. The nutrient solution tanks may be above ground [*Plate* 1] or below ground [*Plate* 2].

Slow Sand Filtration

These are relatively inexpensive to install and operate and easy to run. They are generally used on smaller operations but can be scaled up to treat larger operations.

The size of the sand grains used and flow rate determines how well the system works as well as the size of unit. A smaller grain size provides a more effective filtration but is slow. However, too large a grain size, while increasing flow rate, may be less effective.

A one-hectare greenhouse operation requires 25 m^2 filtration area at 2.5 m^3/hr (flow rate of 0.1 m^3/hr/m^2) while a faster flow rate uses less filtration area — flow rate 0.3m^3/hr/m^2 requires 8.3 m^2 filtration area. The standard filter height is 2.54 m.

This system works because microbes adhere to the sand particles and there is natural suppression by the micro-flora. A slow sand filtration system requires regular maintenance by removing the top few centimeters of sand and adding fresh sand after the height of the first sand layer has been reduced.

Lava Rock Filtration System

The general set-up is similar to slow sand filtration except small sized lava rocks are placed in the filter and air is bubbled into the system [*Plate* 3]. This circulates the lava rocks and aerates the solution. The lava rock filtration maintains the biological balance in the water and has low maintenance and operating costs. These units are smaller than sand filters and are able to treat a larger volume of water at a faster rate.

TABLE 2–7. Size of Lava Filter

Flow Rate (L/hr)	Diameter (m)
900	1.85
2,500	3.1
4,500	4.0
7,000	5.1
13,400	7.0
21,000	8.8

Flow rate determines filter size (Height 1.72 m). Contact manufacturer for precise size.

Heat Treatment System

This system is designed to raise the temperature of the nutrient solution to a set temperature and maintain it for a specific time [*Plate* 4]. The treated solution is cooled by preheating the incoming water in a heat exchanger. This raises the temperature of the outgoing treated water 3°C–5°C above the incoming water. It is fairly simple to use; most operations use a separate heat source for this process rather than the main greenhouse heating system. A temperature of 90°C for 30 sec. will do the job, but usually 85°C for 3 min. is used. The excess heat in the nutrient solution can be a problem in the summer as the nutrient solution may be too warm to be applied to the crop. Blend with cool well water (<15°C) to cool the solution before applying. The pH of the nutrient solution must be dropped to minimize the deposition of salts in the heat exchanger (the additional nutrient component is adjusted for in the fertilizer schedule). An advantage of this system is temperature and exposure time can be monitored and recorded into a computer for better management.

Ozonation System

Ozone (O_3), comprised of 3 oxygen molecules, is a free radical that is very reactive (has 10 times more oxidation potential than chlorine). It is generated on site (air through high-energy electrical field) and requires 8–17 kWh/Kg O_3 generated [*Plate* 5]. Its effectiveness is determined by dose, time and flow rate. Usually a rate of 10 g ozone for 1 hr per 1 m^3 of water is effective. Too low a rate results in poor performance while excessive rates may cause damage to the roots and the crop. Ozone in the nutrient solution will cause manganese (Mn) and iron (Fe) to be precipitated out of the solution and unavailable to the plant. Micronutrient levels in the nutrient solution should be increased accordingly.

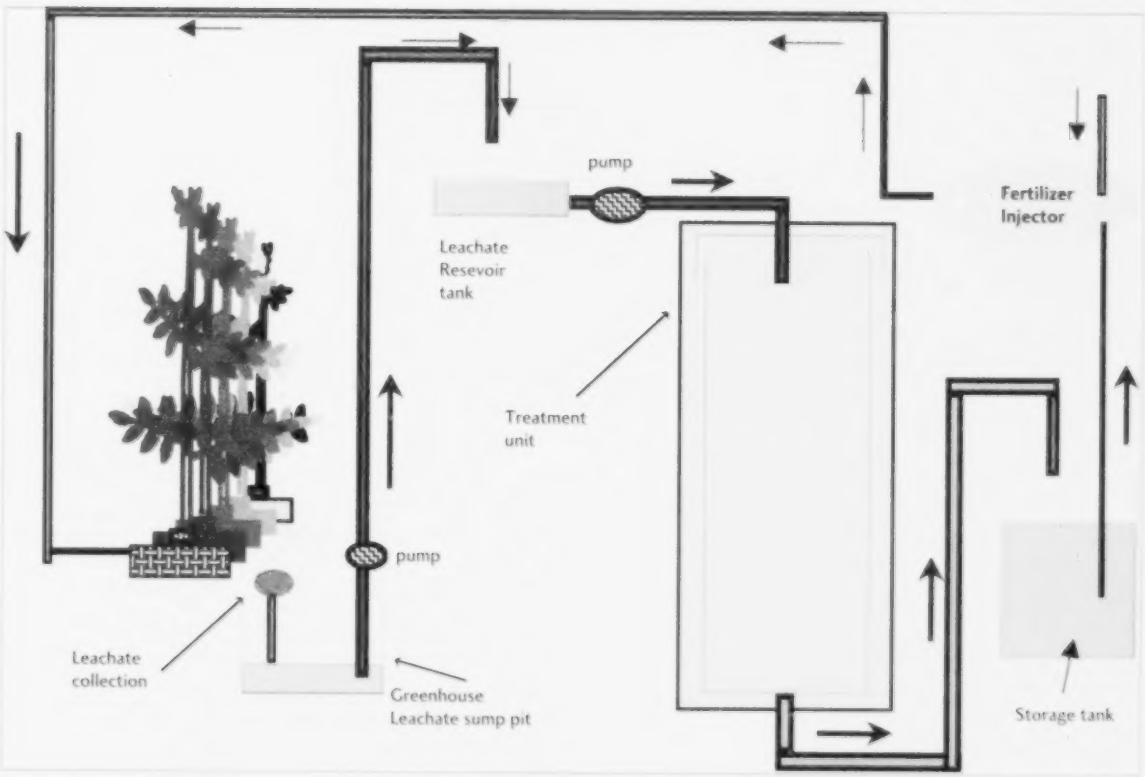
UV Treatment

Ultraviolet systems have been used in the greenhouse industry for many years, especially in the NFT growing systems. The nutrient solution is passed over the UV light bulb (emitting UV-C (254 nm wavelength)) enclosed in a chamber [*Plate* 6]. The system is designed to allow a film of solution to flow over the bulb to ensure good UV penetration. UV does not penetrate too far into the water and is easily reflected or absorbed by materials in the solution. It is important to pre-filter the solution using a sand filter and a

100-mesh inline filter to remove plant debris and particles (reduce turbidity). Normal UV use will cause an organic film to form, as well as iron in the nutrient solution to precipitate onto the light bulb, reducing efficacy. This requires an acid wash and cleaning of the bulb surface. Modern systems conduct this automatically and have sensors that detect the loss in UV emission from the bulb, as well as transmission through the solution, initiating the cleaning cycle automatically. The bulb is soaked in a low pH solution and the wiper is passed over the bulb. This solution is released and the bulb rinsed before the next nutrient solution treatment.

The dose to flow rate is critical, as 100 mJ/cm^2 is required to kill most fungi; 250 mJ/cm^2 will provide complete disinfection.

FIGURE 2–8. Nutrient Solution Recycling Layout



3. Analytic Testing

Since hydroponic systems have a lower buffer capacity, all fertilizers are available to the crop. This means any errors while applying fertilizer are seen immediately. Given the current use of hydroponic production systems for greenhouse vegetables, growers need greater precision in applying fertilizers to their crops.

In general, use an OMAF accredited laboratory for greenhouse media and nutrient solutions to conduct tests. (Appendix D, *Accredited Soil Testing Labs in Ontario*, p. 135) Prices vary between laboratories, as does the service and reliability. Choose a laboratory that provides good, reliable, quick service. The use of on-site testing kits varies as most growers prefer the reliability of commercial labs. While it is acceptable to use colormetric kits and single element testing units to check some nutrients more regularly, defer to the results obtained from the lab tests.

Water Solution and Analyses

Conducting frequent and regular nutrient solution analysis allows trends in the nutrient levels to be detected before problems arise. Submit samples of the nutrient solution applied to the crop, together with samples present in the root zone/growing media.

Once a week, or every 2 weeks, analysis of the:

- feed solution (solution applied to the crop)
- root zone solution (solution extracted from the bag)
- leachate (captured solution leaching from the bag)

provides a check to ensure the correct fertilizer is applied. It also indicates what adjustments are needed to compensate for plant consumption. This becomes more crucial when nutrient solution recycling is practiced.

Weekly analysis of the NFT solution from the reservoir provides similar information. The tests conducted must analyze for both macronutrients and micronutrients at all times.

Tissue/Foliar Testing

These tests provide information regarding the nutrient status of the crop. Regular testing reveals trends allowing corrective measures to be implemented before problems arise. At every 3rd or 4th nutrient/water test, conduct a foliar analysis.

Each crop has a specific leaf used for analysis:

- Tomatoes — the 5th leaf from the growing tip on the main stem.
- Cucumber — the 3rd leaf (10 cm across) from the growing tip, or from a lateral near the upper part of the crop canopy once topping has occurred.
- Peppers — a young, fully expanded leaf about 15 cm from the growing tip.
- Lettuce — a mature leaf.

Wrap the leaf samples in a paper towel, place in a plastic bag, seal and place in a standard brown envelope. Mail or ship by courier to the lab.

Table 3–1, *A Guide to Nutrient Content of Leaf Tissue*, p. 32, provides a guide to the normal acceptable range for greenhouse vegetables.

Soil Testing

In soil-grown greenhouse vegetable crops, conduct soil testing prior to planting to determine both the preplant and post-plant fertility program. Regular testing during the season is essential to ensure crops have received adequate fertilizer.

Soil samples should represent the soil type in the greenhouse. During the growing season, a regular soil analysis every 2 weeks helps maintain the ideal fertility program. Using a soil probe, take samples from several locations in the greenhouse to a depth of 20 cm. Pool and mix these samples together and forward this mixture to the lab for analysis. Taking separate samples where there are different soil types, or

a specific problem area exists, allows for customized fertilizer programs for these locations.

Table 3–2, *Guidelines for Greenhouse Growing Media Analyzed by the Saturated Paste Method*, outlines acceptable nutrient levels in the soil and is a guide for subsequently adjusting the fertility program.

TABLE 3–1. A Guide to Nutrient Content of Leaf Tissue

	Tomatoes	Cucumbers	Peppers	Lettuce
Major Elements (%)				
Nitrogen	4.0–5.5	4.0–6.0	3.5–5.5	4.0–5.0
Phosphorus	0.3–0.65	0.6–1.0	0.4	0.6–0.8
Potassium	3.5–5.0	3.5–4.0	5.0–5.9	7.8–13.6
Calcium	1.6–3.2	2.4–3.2	2.8–3.2	0.8–1.2
Magnesium	0.36–0.5	0.36–0.5	0.5–0.75	0.25–0.5
Sulfur	1.3	0.3	0.5	0.3
Minor Elements (ppm)				
Manganese	55–165	55–165	55	55–110
Copper	5–10	7–12	5–10	6
Zinc	30–50	40–60	30–60	30
Boron	55–75	55–75	55–75	45
Iron	85–110	85–110	112	85–110

TABLE 3–2. Guidelines for Greenhouse Growing Media Analyzed by the Saturated-Paste Procedure

Analysis	Low	Acceptable	Optimum	High	Very High
Soluble salt, mS/cm	0–0.75	0.75–2.0	2.0–3.5	3.5–5.0	5.0+
NitrateN, ppm	0–39	40–99	100–199	200–299	300+
Phosphorus, ppm	0–2	3–5	6–10	11–18	19+
Potassium, ppm	0–59	60–149	150–249	250–349	350+
Calcium, ppm	0–79	80–199	200+		
Magnesium, ppm	0–29	30–69	70+		

4. Growing Media

The growing media must provide four basic needs for the plant: water, nutrients, oxygen and support for the roots. The past decade has seen a major shift from soil culture to hydroponic/soilless culture. Today, most greenhouse vegetables are grown in rockwool (77%), coir (cocos-peat) (13%), and other media such as NFT, foam, expanded clay pellets, peat, sawdust and soil (10%).

Rockwool Culture

Rockwool is an artificial growing media made from basaltic rock, coke and limestone. The basaltic rock is melted in a kiln and the molten rock is spun in threads that are layered to form mats. These are used as insulation in buildings, pipes or for horticultural purposes. Horticultural rockwool is manufactured under strict guidelines to create a uniform product of specific density, treated with a wetting agent and wrapped and sealed in polyethylene bags.

Horticultural rockwool:

- is sterile (free of pathogens, weed seeds, etc.)
- has a low cation exchange capacity/or is inert and does not interact with the nutrient solution
- has a high water holding capacity
- usually has a high initial pH
- is light weight and easy to handle
- allows for a shorter between-crop interval.

Rockwool is a free-draining media. As such it is important to lay out the production system properly within the greenhouse to ensure uniform watering to all plants. If not set up properly some bags may remain wet, restricting plant growth and causing lack of uniformity in the crop.

A basic rockwool production system consists of a:

- ground sheet that isolates the soil surface from the greenhouse growing environment
- styrofoam strip for insulation (placed underneath the rockwool slab and either above or below the ground sheet)
- drip irrigation delivery system, and
- leachate collection system.

Rockwool is available as slabs, blocks, starting plugs and granules. The granules are either used as an additive to peat bag culture to form peat wool or on their own. Granule bag culture is not as popular as slab rockwool culture. Seed is sown in the rockwool starting plugs and after germination, transplanted into rockwool blocks. Once they have reached the desired size and stage, plants in the rockwool blocks are transplanted onto the rockwool slabs in the greenhouse. This process can take up to 6–8 weeks for tomatoes, 3–4 weeks for cucumbers and 7–9 weeks for peppers. This period is longer during winter and shorter in summer.

There are two methods of setting up rockwool culture: open system or closed system.

Open System

In this system, the leachate solution is allowed to run to waste. The soil in each greenhouse is contoured to create a trench between the plant rows, a slight crown along the length of the walkways, and the site of the rockwool slab is level or on a slight slope (i.e., < 0.5%) towards the trench. The trench acts as a drain to collect the nutrient solution. Traditionally, a ground sheet is placed over the contoured soil and the drip irrigation system is placed in the trench for convenience. See Figure 4–1, *Layout for Open System Rockwool*, p. 34 for a diagram of the basic system.

Closed System

In this system, the leachate solution is collected, treated and reused to irrigate the crop. The basic set up is similar to the open system, but the drain trench is sloped at 0.5% towards one end of the greenhouse (Figure 4–2, *Layout for Closed System Rockwod*, p. 34). The base of the trench is lined with plastic. A perforated 'Big O' tube is placed in the bottom of the trench that is then backfilled with clean pea gravel up

to ground level and covered with ground sheet plastic [*Plate 7*].

The size of the 'Big O' tube is determined by the size of the trench. In most cases, a 5 cm (2 in.) diameter tube is sufficient to collect and rapidly drain the leachate water. Rockwool slabs are placed at their specific location, and at every drain hole for the slab, a slit is made in the ground sheet plastic to allow the leachate to escape into the 'Big O'. The 'Big O' is hooked with a 10 cm (4 in.) sewer pipe that drains to a reservoir where the leachate is stored, and treated before being re-used to irrigate the crop.

Numerous other techniques exist to capture leachate. For example:

- flexible plastic sleeves with brackets to keep the rockwool slabs out of the leachate water
- styrofoam shaped to hold the slab with a deeper groove to channel the leachate water away
- preformed aluminum troughs with ridges in the base that channel the leachate
- preformed plastic troughs with leachate drainage channels formed at the base to allow the solution to be captured.

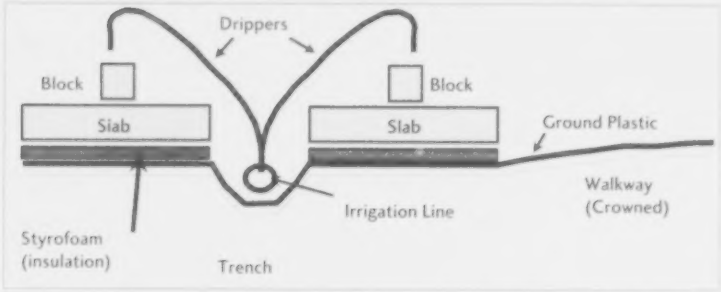
There is an increased trend by growers to use the "V" system, where a single row of rockwool slabs with double the number of plants is placed in the centre of the growing row. The plants are alternately trained to opposite sides of the growing row to form two plant rows. This decreases the amount of rockwool required to grow a crop, although it requires an irrigation system capable of delivering 150–200 mL/m^2/cycle every 15 min.

The advantage of a closed system, where leachate is recycled, is improved fertilizer and water use efficiency. (*Nutrient Solution Recycling*, p. 27.)

After placing the slabs in the greenhouse, the plant location is marked and a round or square hole is cut in the plastic overwrap. Hole size is determined by the size of the rockwool block used. The rockwool itself is not cut. Only the plastic bag is cut to expose the rockwool slab. Prior to transplanting the crop onto the rockwool slabs, a complete nutrient solution is applied to soak the bags thoroughly.

The drip irrigation emitters are placed onto each hole and the irrigation is started.

FIGURE 4–1. Layout for Open System Rockwool

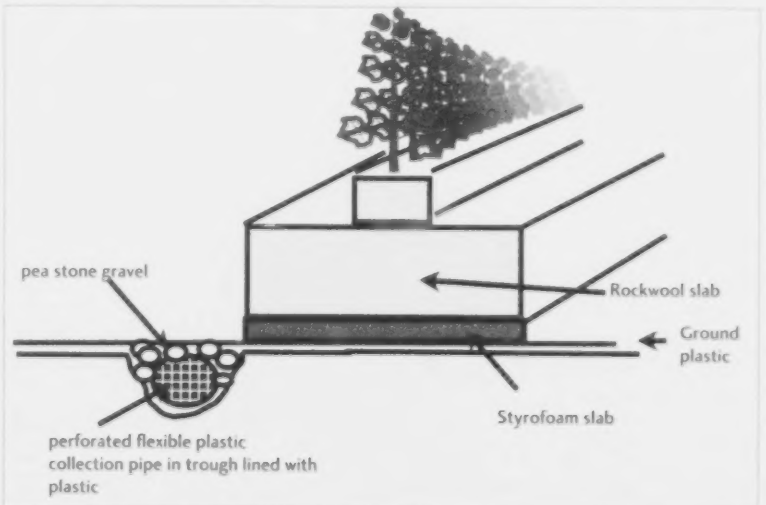


Raised Trough System

The raised trough system is used in most new greenhouses with many older facilities retrofitting [*Plate 8*]. In this system the rockwool slabs are placed in preformed raised troughs, 80–120 cm off the ground, either on stands or hung off chains from the trusses of greenhouses engineered to hold this load.

The raised trough system lends itself to intercropping, where the new crop is planted as the old crop is coming to an end. The final harvest of the old crop coincides with the first harvest of the new crop.

FIGURE 4–2. Layout for Closed System Rockwod



Advantages

- Faster set up during construction phase, as there is no need to form the ground for leachate trenches.
- The greenhouse ground is flat, making pipe rail and track system setup as well as maintenance easier.
- Labour friendly:
  - less bending
  - easier to lay out growing media bags
  - easier to plant
  - deleafing is conducted at an easier working height
  - harvesting is easier and faster.
- Improved pest and disease management:
  - easier to monitor for diseases at base of plant and lower stems and leaves
  - better air circulation allowing for improved microclimate and easier management
  - easier to detect and fix problems with drippers (blockage and leaks)
  - easier introduction of biocontrols at base of plants.
- Water management in growing media is easier because:
  - slabs are level resulting in uniform wetness and draining
  - uniform watering as all the emitters are uniformly placed
  - nutrient solution recirculation is 100% as all leaks etc. are easily detected and repaired.
- Easier to clean up during season (plant clippings) and end of season crop removal.

Disadvantages

- Cost of troughs.
- Greenhouse structure must be designed to hold weight of troughs and plants.
- Algae growth in drain channel.
- Less flexibility to alternate crops.

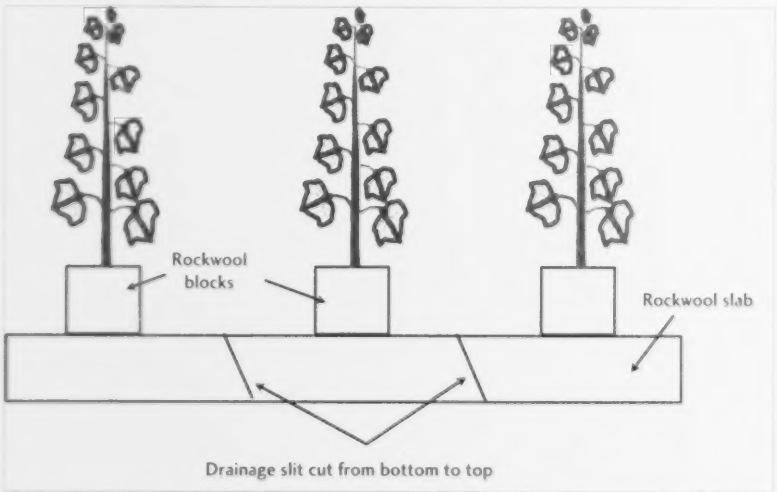
Water Management

Rockwool slabs, although free draining, can become waterlogged. This is especially critical during early plant growth stages and under low light conditions. Set the bags up properly for optimum drainage.

After placing bags in the greenhouse, the bags are saturated with a complete nutrient solution. (See individual crops discussed in Chapters 6, 7, 8 and 9 for specific solutions). The bag must be completely saturated to activate the wetting agent, ensuring the whole slab is available to the plant roots. After planting, cut a slit in the bag from the bottom up to allow for drainage (Figure 4–3, *Drainage Slits on Rockwool Slab for Cucumber*). This is usually done within 24–48 hr after planting. Water the plants for ½ hour and then, depending on the weather, apply no further nutrient solution for 2–3 days. This ensures rapid root penetration into the slab as well as allows the slab to dry out. After 2–3 days, water for 15–min., followed by 2–3 days with no water (depending on weather).

CAUTION: The final degree of slab dryness depends on the characteristics of the slab purchased. Some slabs are characteristically dry and this procedure must not be practiced, or if conducted, must be done with great care.

FIGURE 4–3. Drainage Slits on Rockwood Slab for Cucumber



Subsequently, water as required. The amount of water applied to the crop is determined by several factors:

- stage of plant growth
- light
- temperatures in the greenhouse and in the slab
- RH/VPD in the greenhouse
- amount of air movement.

In general, a 100 mL/cycle is used. This may vary, depending on:

- the type of rockwool
- stage of plant growth
- time of year
- Electrical Conductivity (EC), a measure of the quantity of fertilizer present in the solution, and
- percentage drain.

To determine the correct watering pattern, monitor both the EC in the slab, as well as the percent drain/leachate. Use a large bore hypodermic needle attached to a 50 cc plunger to extract the nutrient solution from the slab. Measure the EC using an EC meter or EC pen.

As well, monitor the percent leachate. Place one or two slabs in a tray with a drain and measure the amount of water that is collected. Usually a leachate or over-watering of 20%–30% is recommended. The percent leachate may be measured electronically or simply by comparing what is added and what is leached out.

The simplest way is to collect the solution applied from a single emitter into a 4 L graduated container and the leachate from four plants in a similar sized and type of container. If the two levels are the same, the rate of leaching was 25% (Figure 4–4, *Leachate Measurement*). Take this measurement at the same time daily, usually before first watering. This allows the watering to be adjusted to obtain the proper root environment.

A daily record of the amount of leachate and irrigated water must be kept. As well, the EC and pH of the irrigation water and the slab must be recorded.

Night watering is usually not recommended. Start the irrigation cycles 1–2 hr after sunrise and end them 1–2 hr before sunset. After the first irrigation cycle, check the slabs for leachate. If there is no leachate after the 3rd cycle, the bags are too dry. Extend the irrigation program later into the evening or start earlier in the day. If there is leachate after the first cycle, the slabs are too wet. Either delay start-up time or end irrigation earlier.

If the irrigation program is not properly set up, the slabs may be:

1. too wet – resulting in:
   - poor aeration of the slab
   - softer vegetative growth
   - poor root growth
   - increased root disease
2. too dry – resulting in:
   - damaged root hairs
   - high EC
   - problems with calcium uptake and movement (blossom end rot (BER) in tomatoes and peppers, leaf scorch/curl on young cucumber leaves)
   - harder growth, thinner plants
   - dark, smaller, thick leaves

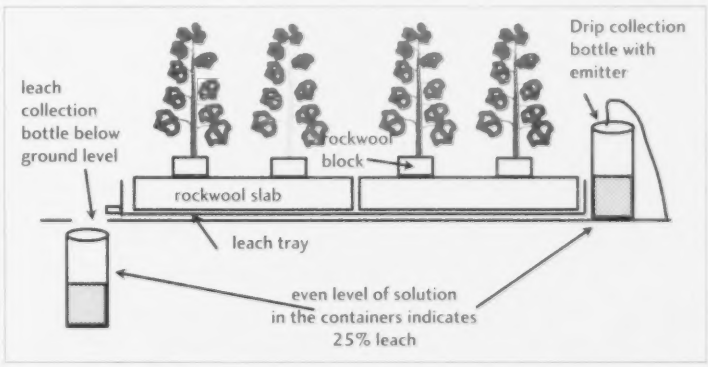
Use either time, start tray or accumulated light radiation to initiate the irrigation cycles.

The rockwool slab water content, EC and temperature may be measured using a unit available commercially. These units are portable and can measure data from several slabs at any time of day and night. The latest models are permanently installed and recorded data are sent directly to the irrigation computer, where adjustments to the irrigation schedule are made.

Fertilizer Schedules

Generally, when used the first time, rockwool slabs tend to have a high pH. Apply a nutrient solution at pH of 5.0–5.5 to allow for this high pH. It usually takes some time before the pH will remain at the desired pH of 5.8. As the rockwool slab is inert, apply

FIGURE 4–4. Leachate Measurements


Drip collection bottle with emitter
leach collection bottle below ground level
rockwool block
rockwool slab
leach tray
even level of solution in the containers indicates 25% leach

a complete nutrient solution at all times. Consult individual crops discussed in Chapters 6, 7, 8 and 9 for suggested fertilizer schedules.

Slab Sterilization

While rockwool slabs may be used for multiple crops, make sure to sterilize the slabs between crops. Shortly before (24–36 hr) the crop is terminated, decrease the amount of water applied and allow the plants to dry out the slabs. Once the slabs are dry and the plants removed, remove the plastic wrap and stack the slabs on pallets [*Plate* 9]. Leave adequate space between slabs for steam to penetrate. Do not stack slabs more than 1 m high to prevent damage to the bottom slabs. Cover the stack of slabs with plastic and introduce steam [*Plate* 10]. Apply a temperature of 90°C for 30 min., measured in the middle of the stack, to disinfect the slabs. To ensure good steam penetration, steam the slabs overnight. Let slabs cool, then wrap in new plastic, seal and place in the greenhouse ready for the next crop.

Coir or Cocos-peat

Coir is a relatively new growing substrate in Ontario that has become popular the past few years due its competitive price and ease of disposal at the end of the cropping season. It is an organic substrate comprised of waste materials from the coconut fibre industry. The long fibres from the coconut husk are removed and the remaining material is screened and graded. This remaining material is spherically shaped of various diameters, has a high water holding capacity, high porosity and medium to high cation exchange capacity. The material has a pH of 5.6–6.5 and a bulk density of 82 kg/m^3. After treatment to remove excess salts, the material is dried, compressed in cakes and packaged in polyethylene bags before shipping.

The same layout as rockwool production is used except for the following.

- Soak bags with a nutrient solution with a slightly higher calcium level and slightly lower potassium level that is similar to rockwool fertigation.
- Before placing plants, fully saturate the coir so the fibres regain their natural state.
- Some coir suppliers have precut bags — ensure complete saturation.
- Water management may vary depending upon the characteristics of the coir.

The particle size and its uniformity in the coir slab determines the water holding capacity and water availability. In some cases the mixture is such that the slab is very generative (requiring more frequent watering), which is better for production when light levels are low; while in other cases it is very vegetative (requiring adjustments to the water regime to prevent overwatering). This variability is present among the different available brands, and in some cases, bag to bag.

Coir re-wets easily and drains quickly, allowing easier steering of the plant. At the end of the cropping cycle coir can composted.

Nutrient Film Technique (NFT)

Nutrient film technique (NFT) is a method of growing plants in a continuous shallow flow of nutrient solution. This technique is a true hydroponic culture, where the bare roots of the plants are bathed in a nutrient solution that is recycled in a closed system. This saves both fertilizer and water, and reduces the impact on the environment.

The basic design consists of a reservoir tank and its various components of pumps, solution delivery network, growing troughs and solution return system. The nutrient solution is pumped from the reservoir to the top end of the growing trough, flowing by gravity to the return line and back to the reservoir. The growing trough is set on a slope of 1%–2% to facilitate the flow of the nutrient solution.

The Reservoir Tank

The reservoir tank for an NFT system is located below grade to allow for a gravity-fed return flow of the nutrient solution (Figure 4–5, *NFT Tank Setup*, p. 38). It may be constructed of:

- concrete blocks
- poured concrete formed into a tank
- concrete crocks buried in the ground, with a cement floor
- rigid plastic tanks buried in the ground or placed as inserts in concrete casings
- a pit with wooden walls lined with a swimming pool liner.

The concrete must be painted with a rubber-based, non-phytotoxic paint to protect the concrete from the nutrient solution.

The reservoir tanks usually have a 5,500 L/0.5 ha (1,000 gal/acre) capacity with 4,000–4,500 L (750 gal) of water in the tank. The traditional NFT system has approximately 13,500–13,750 L or 3,000 gal/0.5 ha in the greenhouse. Provisions may be made to store this water in case of electrical power failure or it may be drained. The tank is equipped with an automatic fresh water intake that allows fresh water to flow into the tank once the level drops below a set amount.

Pump System

The pumping system must be able to deliver a high volume of water (at least 2 L/emitter) at a low pressure, be reliable, and equipped with stainless steel or plastic impellers and components. Normally, systems are designed based on a 5 HP pumping station/acre. A standby pump of equivalent capacity equipped with a sensor to automatically switch it on must also be installed.

A more economical technique is to install three pumps of 2 HP each in parallel, all running at once. If one of the pumps fails, the two remaining pumps are capable of supplying enough solution to the crop to minimize crop injury while repairs are conducted. As a safety feature, keep a spare motor to replace the malfunctioning motor. As electrical disruption can cause crop devastation, all facilities require a standby electrical generator designed to provide adequate electricity to power the pumps and other essential greenhouse features (e.g., heat, vents, computers, etc.).

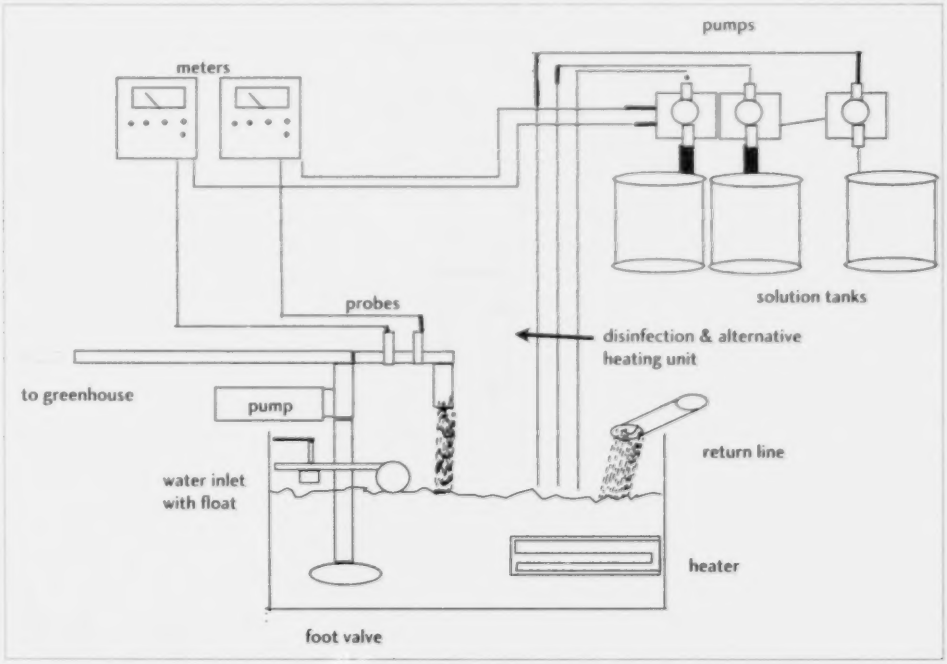
An added benefit of using three, 2 HP pumps is that the extra pumping capacity allows an increase to the solution flow rate of 2 L/min./trough if required. As well the extra capacity can be used to aerate the tanks, send the nutrient solution to the in-line monitoring system, and for heating and pasteurization systems. This removes the need for an extra pump to supply nutrient solution for these purposes.

pH and EC Controllers

The solution pH and EC (electrical conductivity) is continuously monitored by in-line probes and adjustments made automatically. Once the reading varies from the grower-established set point, pH and EC controllers trigger the attached nutrient solution dosing pumps (Figure 4–5, *NFT Tank Setup*). This system adds fertilizer and acids on a continual basis as required. A time-out switch on the controllers prevents over-dosing. This is an important safety feature, as excessive fertilizer or acid can be detrimental to the crop. As a safety measure, install a second set of pH and EC monitors as a check on the primary controllers.

A computerized fertilizer injector system (e.g., Harrow Fertigation Manager©) can also be used to monitor and adjust the nutrient solution. The advantage of such a system is that it can:

FIGURE 4–5. NFT Tank Setup



- monitor several NFT reservoir tanks from a single unit
- maintain the integrity of the nutrient solutions for each NFT system
- allow for different feed schedules (e.g., older crops vs. younger crops) to be maintained in each system.

Heating

The optimum solution temperature is 18°C–21°C. Usually the solution temperature reflects air temperature. An additional heating source to maintain a constant solution temperature is necessary, especially when adding fresh water. Stainless steel hot water heating coils are placed in the reservoir tank or, as in most cases, in a small auxiliary tank. The nutrient solution is supplied to the auxiliary tank off the main pump on a side loop and allowed to return to the reservoir tank after heating.

As the temperature of the nutrient solution increases, the dissolved oxygen in the nutrient solution decreases. This may become a problem in the summer, especially when planting a fall crop. The young plants initially do not provide adequate shade. This allows the radiant energy from the sun to heat the nutrient solution. Temperatures as high as 30°C are not uncommon. Well water is used to cool the nutrient solution.

Pasteurizing Nutrient Solution

A pasteurization loop is installed in the NFT system to allow 25% of the nutrient solution to pass through UV lamps back into the reservoir tank. A complete sterilization of the nutrient solution is not recommended because a sterile solution allows rapid proliferation of microbial populations. A partial pasteurization, while helping maintain a lower microbial population, allows a balance between beneficial and non-beneficial microbial populations to be established in the solution.

Ozonation is another method of disinfecting the nutrient solution. However, it requires specialized customized systems to avoid plant injury and ensure efficiency. This is for the adventurous grower and, as of printing, no installation in Ontario uses this technique.

While slow sand filtration is an effective technique, it cannot provide the volume or the flow rate necessary for an NFT system and so is not used at present.

Aeration

The nutrient solution must be aerated. A large drop between the return line and the level of solution in the tank provides good agitation and helps replenish the oxygen. An aeration loop, using a venturi system, also improves oxygenation by forcing air into the nutrient solution. Injecting oxygen into the nutrient solution is another way to maintain adequate O_2 levels.

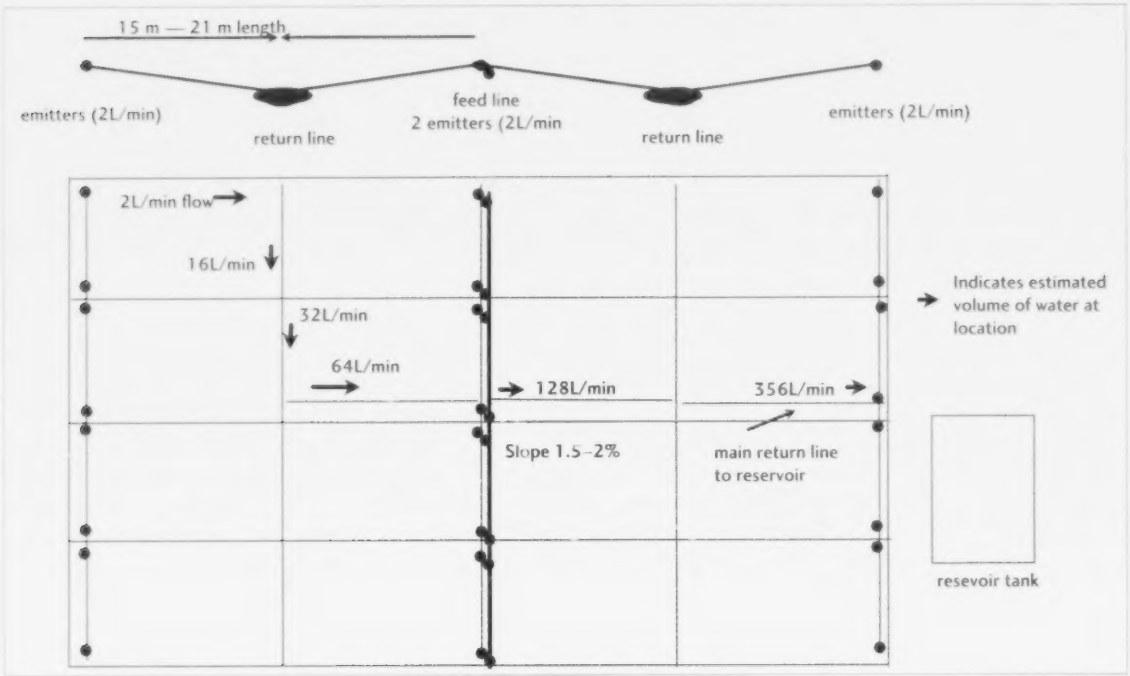
Plumbing–Nutrient Solution Distribution and Collection

The nutrient solution delivery system must be designed to ensure that all troughs receive the same flow rate (2 L/min./trough) (Figure 4-6, *Layout for NFT Emitters and Return Line*, p. 40). A 75 mm (3 in.) main header from the pump set delivers the nutrient solution to 37.5–50 mm (1.5–2.0 in.) subheader. The subheader delivers the solution to a 19–25 mm (0.75–1.0 in.) sub-subheader at each zone from which a 4 mm flexible tube (35–40 cm long) delivers at least 2 L/min. nutrient solution per trough. A well-designed system will require little or no balancing between zones to ensure even water distribution. PVC is used for all plumbing components as the nutrient solution can corrode galvanized pipes resulting in phytotoxicity.

The intakes for the pumps are usually located near the bottom of the reservoir tank and require a basket filter with a one-way check valve at the bottom. This is crucial in case of a power failure, as the pumps do not need to be primed once the generator restores electricity.

The return line is buried in the ground and consists of 10 cm (4 in.) sewer pipe (inexpensive, easy to install and durable). Holes cut into the pipe or "T" junctions located at every trough return location allow the solution to flow from the growing trough into the return line. The solution flows by gravity to the reservoir tank. A 0.5% slope is usually adequate. A large drop between the return line and the top of the nutrient solution is necessary to ensure maximum mixing of the return solution with that of the reservoir. The increased agitation enhances solution aeration helping to ensure adequate oxygen for the root system. As well, baffles placed at the end of the return line may also increase agitation to improve aeration. A coarse filter (e.g., a nylon stocking placed over the opening) will trap any root pieces, etc., that may clog the pump impellers.

FIGURE 4–6. Layout for NFT Emitters and Return Line



Growing Trough

Numerous types of troughs are available. These vary from aluminum troughs with plastic covers, preformed rigid plastic troughs with flaps, to 6-mil white on black polytubes. In all cases, the purpose of the trough is to provide a channel for the nutrient solution to flow and the roots to grow in. The least expensive system is the 6-mil poly tube laid on 4 cm (2 in.) styrofoam (20 cm wide). A wide shallow groove, running along the length of the styrofoam, channels the nutrient solution towards the middle of the trough. This is especially important in the early stages of the cropping cycle to ensure that all plants receive nutrient solution. However, too deep a channel results in poor aeration, decreasing the amount of oxygen available to the roots, decreasing performance and encouraging root die-back and diseases.

Ideally the trough should have a slope of 1.5%–2%, be 15 m (50 ft.) long and 30 cm (12 in.) wide at the base. Do not have the trough longer than 21 m (70 ft.) without modifying the design of the system.

Phytotoxicity

It is important to ensure that all components of the NFT system are non-phytotoxic. Do not use metal components (galvanized pipes or copper pipes) as they corrode and release micronutrients, such as zinc or copper, which will accumulate to toxic levels. Plastic components in the irrigation lines, as well as the growing trough, must be non-phytotoxic.

Components in some flexible plastics are extremely toxic to plants.

Soil Culture

The number of growers producing in this medium has declined. However, some smaller greenhouse operations in isolated areas continue to produce good greenhouse vegetable crops. Drip irrigation or tape irrigation is commonly used to grow soil crops in the greenhouse.

Type of Soil

A well-aerated soil with good drainage, rich in nutrients, high in organic matter content and free of pathogens is needed to achieve maximum production. Soils most suited are loam, sandy-loam and some silty loam types. Other soil types may be used but require proper management and increased input costs to achieve maximum productivity. For example,

early winter production in a heavy clay soil requires installation of tile drains, increasing organic matter content before the cropping season to aggregate soil particles, and careful water and nutrient management to achieve success. Sandy soils with poor water holding capacity require frequent watering (with nutrients), which leads to increased potential for ground water contamination. This problem can be overcome with a collection system designed to catch and recycle the excess water.

Drainage

A well-draining soil is best for greenhouse vegetable production. A tile drainage system installed in ground beds ensures all excess water is carried away. Contact a local agricultural drainage company to help design the system. Generally, a 10 cm diameter tile 35 cm deep and 45–60 cm apart with a slope of 10 cm in 150 m is adequate.

Flooding and Leaching

Prior to planting the soil is cultivated to bring it to field capacity. The amount of water required to do this varies depending upon the soil type and the soil moisture content at the time. In general, use 20–50 L/m^2. Water leaching (100 L./m^2) may be necessary in some soils, especially those that were steam pasteurized, to lower high levels of ammonium and manganese.

Soil Pasteurization

Harmful pathogens (bacteria and fungi) are present in most soils, along with weed seeds and insects. Soil pasteurization will eliminate them. Soils should be in fine tilth to allow rapid, uniform penetration of the steam or fumigant. Large clods or lumps of dirt and undecomposed crop remains (stem and root) may hinder full penetration.

Temperatures of 60°C for 30 min. under ideal conditions eliminate most organisms (except viruses) of concern to the grower (Table 4–1, *Time-Temperature Requirements to Destroy Undesirable Organisms*). Over-heating (above 82°C) eliminates beneficial organisms as well, and causes the soil to become sterile and subject to a greater degree of infection than previously.

Other undesirable side effects of over-heating are:

- excessive ammonia release
- manganese toxicity
- destruction of organic matter
- higher total salt level.

TABLE 4–1. Time–Temperature Requirements to Destroy Undesirable Organisms

	Time (min.)	Temperature (°C)
Weeds (most)	15	70 – 80
Insects + mites	20	60–71
Bacteria (most)	10	60
Fusarium	30	57
Botrytis	15	55
Nematodes	15	55
Rhizoctonia	30	50
Sclerotina	5	50
Pythium	40	46

Greenhouse soils can be steam pasteurized by injecting steam through agricultural tile drain (top of the tile 30–40 cm below the soil and 46–60 cm centres). Covering the soil surface with a plastic sheet to trap the steam in the soil greatly enhances its effectiveness. Alternatively, if the drain tile is in disrepair, steam can be injected directly under a specially formulated plastic steam tarp. The edges of the tarp are buried 10–12 cm so the steam, injected at 41–48 kPa (6–7 psi) pressure can be confined. The temperature of the soil must be monitored to ensure that an adequate temperature has been achieved to pasteurize the soil, and that it is not under- or over-heated. (Always leach the soil after steam pasteurization.)

Chemical fumigants may also be used, although the choice is limited. Follow manufacturer's label direction for rate, duration and venting periods to safely and effectively use these products.

Organic Matter

A high level of organic matter helps maintain a stable soil structure and improves water holding capacity and aeration of the soil. Coarse peat at rates as high as 500 m^3/ha may be applied to new soils to improve their condition. Peat is acidic (pH 4.0) and lowers the pH of the soil. This is a benefit for alkaline soils but must be corrected in acidic soils by adding lime (5 kg of limestone/m^3 of peat).

The decomposition rate of organic matter in greenhouse soils is quite high. Apply an annual rate of 100 m^3 of peat/ha. Incorporate both peat and lime in the soil prior to the main cultivation. Composted

manure may be incorporated to aid organic matter content management, but losses due to weed and herbicide contamination may cause severe crop losses.

pH Control

Greenhouse vegetables grow reasonably well within a wide range of soil pH (5.5–7.5) but a pH of 6.0–6.5 for mineral soils and 5.0–5.5 for organic soils is generally accepted as optimum. Use either ground calcitic limestone (3 tonnes/ha for each 0.5 pH unit increase for most light soils) or dolomitic limestone (if soil magnesium level is low) to raise the pH of the soil to the desired level.

Adding peat to the soil for organic matter amendment lowers the pH of high pH soils. Apply annually to make up the loss due to decomposition. Alternatively, add elemental sulphur (flowers of sulphur) at 50–100 kg/ha for each 0.5–1.0 unit of pH decrease. Or apply ordinary sulphur to the soil and incorporate into the top 15–30 cm of the soil. Do this several weeks before planting. The reaction will be slow on cold soils. The amount of sulphur varies between soils depending on the buffering capacity (exchange capacity) and the original pH of the soil.

The pH of the soil around the plant roots is more critical. Adjusting the pH only at the plant site can easily be accomplished when drip irrigating the crop with a complete nutrient solution at pH 5.5 using phosphoric and nitric acid. This will maintain clean irrigation lines and drippers, as well as lower the pH around the root zone enhancing plant growth.

Drip Irrigation

This system:

- allows a regulated control of water and fertilizer to the crop
- reduces humidity of the greenhouse
- allows the use of white polyethylene film as a light reflecting mulch, and
- keeps the product clean.

The irrigation system is designed to deliver nutrient solution to each plant through a series of pipes with in-line emitters or hose-end drippers at 2 L/hr. A nutrient solution containing all required fertilizers is applied 3–4 times/day to meet the water and nutrient needs of the plant. Adjustments to the fertilizer composition (type of fertilizer and quantity) and the volume of water applied varies depending on the type of crop grown, stage of crop, time of the season, light level, temperature of the greenhouse and the water holding capacity of the soil. Daily evaluation of the soil condition approximately 10 cm away from the plant and 10–15 cm deep helps determine the beginning and length of irrigation cycle. The pH and EC measurements of this sample also help indicate nutrient status of the soil.

The soil sample is mixed with tap water (1 part soil to 2 parts water) and the pH and electrical conductivity are measured. A pH reading of 5.5–6.5 and an electrical conductivity reading 0.9–1.2 mS/cm is considered ideal. Information from these quick home tests will assist in determining the amount of fertilizer and water required by the crop.

A laboratory soil analysis of a composite soil sample taken from several locations in the greenhouse helps set the required fertilizer schedule. In the early stages of the cropping cycle, conduct this analysis weekly and every 2–3 weeks after that. More frequent testing may be necessary if crop production problems occur.

5. Plant Raising

A proper start at this stage of the cropping cycle is essential to obtain a uniform, high yielding crop that produces a good quality product. A poor start invariably results in a poor or less than satisfying finish, requiring extra work to obtain a good crop and results in lower economic returns. There are three critical phases:

1. seed
2. sowing and germination
3. transplant raising to a finished product.

Seed

Use seed of the highest quality to ensure a good start. Most seed supplied to the greenhouse vegetable industry has been cleaned, usually treated, and tested for germination/viability. This information is usually printed on the package or is available from the seed supplier. The germination test is conducted by a certified seed laboratory and is performed under strict, standardized guidelines. Germination is defined as the emergence of the radicle from the seed coat. In most cases, the percent germination varies from 75%–90% for tomatoes, 95% for cucumber, 85%–95% for peppers, and 95% for lettuce. Germination percent may vary dramatically depending upon the growing conditions where the seeds were produced. Thus, the number of seed ordered must be adjusted accordingly.

To the grower or plant raiser, a more critical value is the percent emergence — defined as the ratio of the number of seedlings emerged from the growing media to the number sown. This value may vary quite dramatically and is influenced by numerous factors:

- seed vigour
- depth of sowing
- moisture of media
- media aeration
- media temperature.

The difference between percent germination and percent emergence may vary as much as 10%–20%.

Note that rate of seed germination varies dramatically, with some seeds germinating very rapidly while others are slower. Seeds can be grouped into three categories:

Category I	Category II	Category III
seeds emerge 2–3 days after sowing	seeds emerge 3–4 days later	seeds emerge later; have twisted cotyledons, blind shoots, etc.

The percent in each category varies with species, cultivar and seed quality, and fluctuates yearly. For example, the percent emergence may look like this:

Category I	Category II	Category III
73	10	10

The remaining 7% did not emerge.

Categories I and II are true emergence and only these are planted. To have an adequate number of plants, at least 25% more seeds are sown. This allows for some spare quality plants in case of loss due to handling, etc. In general, the following is suggested:

	# Plants Needed	# Seeds Ordered
Tomato	10,000	12,000–13,000
Cucumber	6,500	7,500*
Pepper	10,000	12,000–13,000
Lettuce	1,000	1,100–1,200

* Cucumber seed, in general, have a higher percent germination and emergence.

Sowing and Germination

Sowing seed is a simple but critical step of plant raising. A growing media with good drainage, water holding capacity and aeration such as rockwool or oasis plugs is ideal. These are available in various sizes,

in styrofoam trays or plastic flats. If reusing, thoroughly disinfect before use.

Place seeds on the dimpled surface or in the hole of the plug and cover with medium vermiculite. An even sowing depth is essential to ensure uniform emergence and seedling development. Seed placed too deep in the growing media may take 2–3 days longer to emerge, and may be weaker and slower to develop true leaves. Seed placed on the surface is prone to drying out or in some cases the radicle may not anchor properly, causing seedlings to fall over.

Prior to sowing, pre-soak the growing media with clear water or a dilute complete nutrient solution (EC 1.0–1.5 mS/cm) at 20°C–25°C. After sowing, gently water the growing media to dampen the vermiculite. Ideally, place the flats/trays in a germination chamber or alternatively on benches with heating under the flat or bench heating. Cover the flats on the benches with a 2-mil clear polyethylene sheet to prevent drying out [*Plate* 11]. To ensure uniform, rapid emergence, maintain the ideal media temperature found in Table 5–1, *Germination Temperatures*.

After 60%–75% emergence occurs, remove either the flats/trays from the germination chamber or the poly cover. This is usually done 60–96 hr after seeding, depending on the type of crop and cultivar grown (Table 5–2, *Approximate Hours for Germination*). If this change is carried out too early, emergence of Categories II and III seeds will be delayed and if too late, it will result in the stretching of the earlier emerged Category I seedlings. Once maximum emergence — more than 80% — occurs, gradually lower air temperature to 19°C–20°C for tomatoes (1°C/day in general), 21°C for cucumber and 20°C for peppers. Adjust temperatures according to light incidence (chap. 2, p. 21) to obtain the plant at the desired time. Too large a day/night temperature fluctuation results in elongated plants.

TABLE 5–1. Germination Temperatures

Crop	Temperature*
Tomato	25°C
Cucumber	27°C
Lettuce	16°C–18°C
Pepper	26°C

* Growing media temperature.

Once the true leaves emerge, water the flats with a complete nutrient solution, starting at 1.0 mS/cm EC, and gradually raising the EC to about 3.0 mS/cm

TABLE 5–2. Approximate Hours for Germination

Tomatoes	
Good germination	72 hr
Poor germination	96 hr
Peppers	72–96 hr
Cucumbers	48–60 hr
Lettuce	72 hr

prior to transplanting. Overwatering results in poor aeration of the media, creating inadequate root development. As well, excess moisture (especially applied as a mist) causes the root zone temperature to drop, delaying growth and increasing variability. If the media is too dry, plant growth decreases, leaf size reduces, and the EC of the media increases. The weaker plants may not survive, or if they do, will be more prone to disease incidences.

Transplant seedlings into rockwool blocks once they reach the desired size. Too long a period in the flats (more than 3 weeks for tomatoes and peppers, 1.5 weeks for cucumbers) results in overcrowding, stretching and weakening of the seedlings.

Supplementing with CO_2 and high-pressure sodium light improves growth and helps establish good roots.

- Under good light conditions, supplement CO_2 to 1,000 ppm. As seedlings are extremely sensitive, it is essential to use a clean CO_2 source, such as liquid CO_2.
- Supplementary light at 20 watts/m^2 using high-pressure sodium lights enhances seedling development. Apply an 18-hr photoperiod for tomatoes, peppers and lettuce, and a 24-hr photoperiod for cucumbers.

Transplant Raising

Seedlings are ready to transplant when the first true leaves have fully emerged and/or when the seedlings touch.

Average times are: tomatoes at 14–21 days, cucumbers at 10–14 days and peppers at 17–24 days.

The time required varies depending upon:

- the cultivar
- seedling vigour
- light
- temperature

- nutrition and
- moisture.

A short sturdy seedling is desirable. A seedling with a thick stem, dark green leaves and a well-developed root system filling the plug is ideal. Pop the seedlings out of the tray using a plug popper. Prior to removing plugs, soak the trays with nutrient solution to allow the plugs to easily slide out of the tray. Handle the seedlings carefully. The stem may be very brittle or soft and easily damaged. Handle seedlings by the cotyledons.

Soak the rockwool blocks thoroughly with a complete nutrient solution (EC 2.0 mS/cm; pH 5.8) by dunking the blocks in a tub or by overhead watering before transplanting seedlings. It is important to soak the blocks thoroughly and uniformly to ensure proper seedling establishment. Dry blocks restrict root development and growth, increasing plant to plant variability.

Place seedling plugs in holes in the blocks. If, in some cases, the seedlings are too tall, fold the lower part of the stem into the hole and push the root plug down to fill the hole. This is a common practice for tomatoes, and increasingly with peppers. Roots will develop along the stem within the hole, anchoring the seedling and resulting in the cotyledonary leaves being closer to the surface of the rockwool block. This gives a sturdier transplant.

Place the transplants in trays (4–8 blocks/standard flat) or place directly on the floor (ebb and flood system) or bench at 24–36 plants/m^2 and distribute in the starter house. To ensure good rooting, place trays on benches with bottom heat (or directly on heated concrete floors) [*Plate* 12]. Transplants are ready for planting directly onto the rockwool slab, growing media bag or NFT troughs in the main production area when:

- tomatoes — 1st flowers are showing
- cucumbers — 4–5 true leaves are visible
- peppers — when flower at first branching level is opening.

NOTE: Roots must be well developed in the block and not overcrowded.

If needed, support the plants using a 20–30 cm thin bamboo stake. This encourages development of larger transplants that are more easily handled and allows more time before plants need to be tied after transplanting.

Alternatively, new transplants can be moved directly into the production houses. Place the blocks on the rockwool slab beside the hole and the drippers in the block. Use the irrigation system to water the blocks. This method saves on labour, but costs more to heat the whole greenhouse operation.

After transplanting, maintain greenhouse temperature at 23°C–25°C, 24 hr/day for 4–5 days and then gradually lower the temperature. (See individual crop sections for specific temperature regimes.) In a starter house, supplementary lighting at 20 watts/m^2 and CO_2 at 1,000 ppm increases the rate of root and shoot growth, resulting in earlier flower bud development. Keep a photoperiod of 18 hr for peppers and tomatoes and 24 hr for cucumbers. Since it is not cost-effective, plants placed directly into the main production greenhouse do not receive supplementary light. But they benefit from supplemental CO_2 —1,000 ppm on sunny days and 400–500 ppm on cloudy days.

Water transplants with a complete nutrient solution starting at a low EC (2 mS/cm) and gradually increase (0.250 mS/cm/day) to 3 mS/cm, similar to emerged seedlings. Further increases in EC are determined by:

- the rate of plant growth
- available light
- temperature
- RH
- moisture in the block.

Water in a timely manner. This ensures that leaves are not wet for extended periods of time, especially later in the day. Use either overhead watering or sub-irrigation. Use the weight method, described below, to determine when to water.

When to water

Measure the weight of several blocks with transplants when saturated. Monitor the weight daily and begin watering when the average block weighs 50% less than when saturated. For a 10 × 10 × 7.5 cm block, this is approximately 300–350 g. When watering, ensure the blocks are re-saturated.

Transplants placed directly in the production greenhouse dry out sooner because of the lower relative humidity in the greenhouse (loss of water from the surface of the block as well as due to transpiration). This requires more frequent watering. Night

watering may be necessary on cold nights when the humidity in the greenhouse is low.

Grafting

Grafting of desired cultivars onto rootstocks with stronger root systems is increasing in the greenhouse industry. By far, tomatoes are grafted more frequently than cucumbers and peppers.

Grafting is used to:

- overcome shortcomings in the disease tolerance/resistance of the desired cultivar
- improve plant vigour and performance over a wider range of greenhouse climatic and root zone conditions.

A desirable cultivar (scion) is attached to a rootstock selected for its strong root system with higher disease resistance.

Most commonly used rootstocks for tomato production in Ontario are Beaufort and Maxifort with some Big Power.

Following are the procedures required to successfully graft:

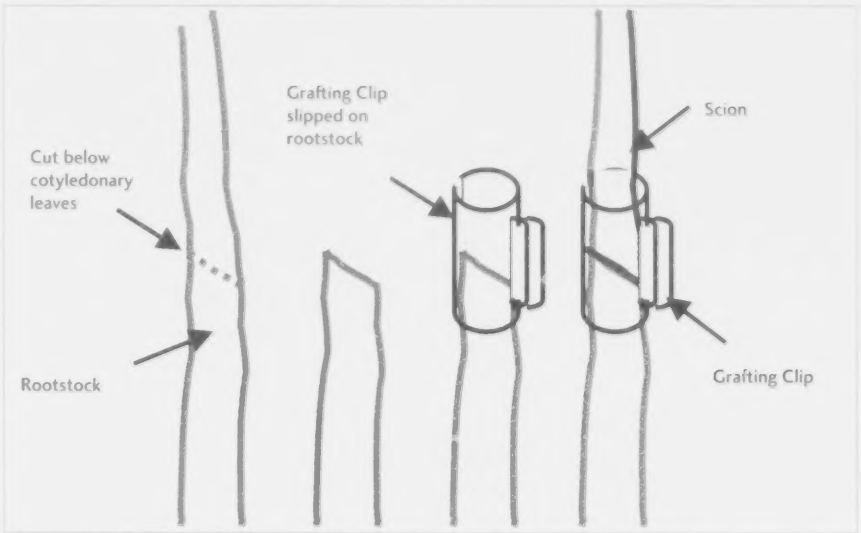
- Sow rootstock seed 4–10 days before sowing the desired cultivar. This difference will depend on the rootstock used (check with the OMAF greenhouse specialist or seed supplier for more details).
- After true leaves begin to emerge, lower temperature for a few days to strengthen stems (about 14–15 days after sowing).
- After 2–3 days, cut rootstock at 45-degree angle using a sharp razor blade below the cotyledon leaves.
- Place clip at cut surface of the rootstock.
- Similarly cut desired cultivar (approximately same diameter as the rootstock) above the cotyledon leaves and slip the scion into clip attached to rootstock. Align cuts to match so the cut surfaces are touching. ***Cuts must match to ensure success*** [*Plate* 13] (Figure 5.1, *Schematic of Japanese Top Grafting*).

NOTE: This procedure is conducted in an aseptic environment. A sterile work area and equipment must be maintained at all times. Do not delay the grafting process once started.

- Place grafted seedlings in a controlled environment where light, temperature and humidity are controlled to minimize water loss from the grafted seedlings and to promote rapid knitting of the rootstock to the top.
- After 3–4 days, gradually acclimatize the grafted seedlings to ambient conditions over the next 3–4 days.
- Transplant into blocks (10–12 days after grafting).
- Use normal transplant raising techniques to grow the plants and once desired plant height and development stage have been achieved, transplant into production area.

Grafted plants tend to be vigorous and must be grown in a manner to create a generative plant. If this is not achieved, the first set may have misshapen flowers, poor quality fruit and size, or in a worst case scenario, aborted flowers.

FIGURE 5–1. Schematic of Japanese Top Grafting



6. Tomato Crop

Tomatoes are the most widely grown produce in Ontario's greenhouses. Since the early 1990s, nearly all tomato production has been the beefsteak-type tomato, which is a large fruited, red coloured tomato. The optimal fruit size is 200–250 g (28–34 count/6.8 kg (15 lb.) box). From the mid 1970s until late 1980s, the pink coloured tomato was widely grown. This tomato was geared for a specific market and had resistance to Fusarium crown and root rot that afflicted the Ontario greenhouse industry in the 1970s. Consumer demand, as well as the transfer of the disease resistance to the red coloured tomato cultivars, accelerated the change, resulting in little or no pink tomato production in Ontario.

Further change in consumer preferences has seen the increase in cluster tomatoes (tomatoes on the vine — TOV) production. This is a slightly smaller tomato than the beefsteak-type and is harvested on the truss/cluster and marketed as a bunch. As well, speciality-type tomatoes such as Roma-type, cocktail, cherry, yellow and orange coloured tomatoes are grown for niche markets.

Two crops of tomatoes are traditionally grown per year. The spring crop is planted in the greenhouse the last week of December, with harvest beginning in mid-to late March and crop termination in July. A fall crop planted in August follows, harvest begins in October, and the crop is terminated in November or December. There is an increase in intercropping to decrease downtime (*Raised Trough System*, p. 34). Alternatively, a single long-season crop is grown, with planting in mid-December, harvest beginning in mid-to late March, with the crop finishing in September/October. The single crop system is most common in the Leamington area, while the two-crop system is used throughout the rest of the province.

Operators adjust the start and finish of the crop to suit market demand, as well as available light. The trend to earlier planting continues as design of greenhouse structures and climate controls improve, and early price remains high. Producing marketable tomatoes during the winter months — November, December, January and February — can be carried out using artificial lighting, but requires a strong capital investment, low electrical rates and high returns at the marketplace to be successful.

A good start by the crop is required to achieve successful tomato production. Healthy transplants with well-balanced growth during the winter months can result in excellent production of high quality fruit. It is the grower's challenge to balance between vegetative and generative growth. An overly vegetative crop has a large leaf area, delayed flowering, poor fruit set and smaller fruit, delayed harvest and is more prone to diseases. A plant that is too generative has a high fruit load, smaller leaves, a weaker growing point, resulting in poor and delayed fruit set until the fruit load is decreased, and overall lower production.

Cultivar Selection

There are a limited number of tomato cultivars suitable for the Ontario greenhouse industry. The consumer demand for a high quality, large-sized red tomato limits the choice. Some characteristics to keep in mind are: yield, fruit size, growth habit, resistance to russeting (shrink cracking), short calyx, fruit firmness, taste and plant habit. Several new cultivars are available, but require further development in the genetics as well as improved cultural practices. Powdery mildew tolerant cultivars are available and may become more important in the future.

Contact your OMAF greenhouse vegetable specialist, the OMAF website at www.omaf.gov.on.ca or your seed company for more details on tomato cultivars.

Cropping Schedule

There are two common cropping practices in Ontario: a spring-fall crop or a long-season crop.

Adjust sowing and planting dates depending upon available light and market commitments. Cropping schedule for a winter crop with artificial lights is as follows:

Crop Type	Sow	Plant	Harvest	Terminate
Spring-Fall Crop				
spring	mid Nov.	1st wk. Jan.	mid to end Mar.	mid July
fall	late June	1st wk. Aug.	Sept./Oct.	end Nov./ mid Dec.
Long-season Crop				
long season	1st wk. Nov.	3rd–4th wk. Dec.	mid–end March	end Sept./ early Oct.
overwinter crop	late June	1st–2nd wk. Aug.	Sept./Oct.	1st wk. June

Seeding

Sow tomato seed directly into rockwool plugs in styrofoam trays or plastic plug trays. Small operations sow seed by hand while automatic seeders are used in larger operations. Soak plugs with plain water or a complete nutrient solution at EC 1–1.5 mS/cm prior to sowing. Cover seed with medium grade vermiculite. Place trays in germination chambers maintained at 24°C–25°C and 100% RH, or on germination benches with under bench heat and cover with a 2-mil clear polyethylene sheet to maintain temperature and humidity.

Optimum germination temperature for tomatoes is 24°C–25°C. Seed emergence occurs 2½–3 days later. After 60%–70% emergence, remove trays from the germination chamber or the plastic film from the flat on the germination bench. Maintain temperature at 24°C for 1–2 days longer and then gradually lower to 19°C–20°C day and night over a 2-day period. After the cotyledonary leaves have expanded, fertilize seedlings with a complete nutrient solution at an EC of 1.0 mS/cm, and gradually increase as the plants develop.

Seedlings benefit from supplementary lighting (18 hr photoperiod at 20 watts/m^2) and CO_2 levels of 800–1,000 ppm.

Begin transplanting 14–21 days after sowing or when the leaves are touching.

Use a pure source of CO_2 as seedlings are extremely sensitive to by-products of improper combustion of carbon fuels.

Plant Raising

Transplant seedlings into 7.5 or 10 cm rockwool blocks with preformed holes to accommodate the rockwool plugs. First soak blocks with a complete nutrient solution, pH 5.5 and EC 1.5– 2.0 mS/cm. At each subsequent watering, gradually raise the EC to eventually reach 3.0–3.5 mS/cm. Adjust the EC according to the available light, rate of growth, plant vigour, available moisture and temperature regime followed.

Place seedlings into the hole of the rockwool block either straight or fold by bending the stem 90° or 180°. By bending the seedling, the cotyledonary leaves and the growing point are placed closer to the surface of the rockwool block. This allows for root development along the buried stem providing greater plant stability.

If seedlings are placed straight up in the hole, they must be staked. Stake with a thin bamboo stick, close to the seedling. Use elastic bands or metal rings to hold the plants to the stake. Cover hole with a layer of medium grade vermiculite for added stability.

As the stake provides support, staked plants can be allowed to grow bigger. This delays the need to tie the plants up to the overhead wires. There is also less damage to plants when transporting at transplanting time.

Maintain greenhouse temperature at 23°C–25°C for 1–2 days after seedling transplanting to hasten root establishment. Following this, gradually lower the temperature to 19°C (day and night) at a rate of 1°C/day. Supplementary light (18 hr photoperiod at 20 watts/m^2) and CO_2 levels of 800–1,000 ppm benefit the crop by producing stronger rooted transplants that are compact with sturdier stem and earlier flowering.

Transplants are ready to plant in the production house when the first flower clusters are well established and/or the first flower begins to open, about 6–7 weeks after sowing. During early stages of tomato

plant growth, the plant tends to be strongly vegetative. To ensure early, high quality production it is important to provide proper cultural conditions to induce the plant to a more generative (flower production) growth phase. Alter temperature, relative humidity, water and fertility in relation to the available light to control the plant [*Plates* 14A, 14B].

A well-established first flower cluster decreases the possibility of the plant being too vegetative after transplanting in production greenhouses. If transplanting occurs too early or the plant growth is not controlled, the plant remains too vegetative. This results in delayed flowering and first harvest, a tendency for smaller, misshapen fruit and a plant more prone to disease infestation. On the other hand, a plant that is too generative results in strong flower production, a weak top, slower growth and delayed harvest. The objective at this stage is to strike a balance between generative and vegetative growth.

Since 2002 there has been an increase in the number of growers using grafted tomatoes to help combat root diseases and improve plant vigour during summer and fall, especially when growing a single long season crop (*Grafting*, p. 46). It is important the early growth of the grafted plant be controlled to produce a balanced plant to ensure early high quality tomatoes.

Plant Spacing

In general, a plant spacing of 0.37–0.41 m^2 (4.0–4.9 $ft.^2$ per plant) or 2.4–2.7 plants/m^2 is ideal. Arrange plants in a twin-growing row 0.6–0.8 m apart, with a 0.9–1.2 m walkway separating the twin growing rows. Plant spacing within the row is adjusted to achieve the desired plant density. In rockwool culture, use 2 plants/90 cm slab with the bags spaced within the row.

When light levels are higher later in the season, plant density may be increased to 2.9 stems/m^2 by allowing a side shoot to develop into a productive stem on every 5th plant. However, care must be taken as this tends to alter the plant:rockwool volume:water interaction, resulting in smaller sized fruit, and increased disease incidence, especially when light levels are poor. Developing and training an extra side shoot to increase stem density is normally initiated in March and works best in a "V" system.

Pruning and Training

Prune greenhouse tomatoes to a single stem. Remove all side shoots or suckers at least once a week. Support the plants with polypropylene twine. Tie one end of the twine loosely to the base of the plant with a small, non-slip loop and attach the other end to an overhead supported wire 1.8–2.5 m above the plant row.

In newer greenhouses equipped with hot water pipe rail systems and scissors carts, overhead wires are 3.0–3.5 m high. Proper tying of the twine at the base of the plant is important as too tight a knot may choke the plant or, if too loose, the plant falls and snaps the stem.

In some cases, the twine can be placed between the bottom of the transplant block and the top of the rockwool slab, so the weight of the plant keeps the twine in place. Loop the twine around the plant as described above. However, problems can develop with wicking of the nutrient solution up the twine. This damages the plant where the twine and stem are in contact, resulting in a loss of production. These are potential sites for diseases such as Botrytis to occur.

As the plant grows, twist the plant around the twine in one or two easy revolutions for each fruit cluster. Once the plants are larger and heavier (usually 4th – 5th cluster), use plastic snap-on clips to attach the plants to the twine. For the spring crop, drape an additional 2.0–2.5 m of twine over the top wire. As the plant reaches the wire, untie the twine and lower regularly, allowing the lower section of the plant to lie on the ground or on wire supports. Overhead hooks, with a season's supply of twine stored on them, are also available and are commonly used in high-wire tomato production houses. These increase the ease of lowering of the crop when layering.

The lower leaves of the tomato plant are removed to:

- improve bottom air circulation
- maintain ideal environment at the base after the plant is lowered
- allow workers to find the fruit easily when harvesting.

Usually, remove only 1–2 leaves at a time, as too many leaves removed all at once alters the leaf:fruit ratio and adversely affects yield. In general, a maximum of 1.2 m (20–22 leaves) of leaf bearing stem is recommended at all times. In some cases, only 12–15 leaves are recommended to maintain rate of fruit development and fruit quality. Aggressive deleafing may be required with some cultivars. In this case remove a leaf

in the middle of the plant and another near the growing point when the plant is approximately at the 3rd–4th flowering truss stage. This may need to be repeated until plant vigour is controlled (especially a problem in fall grown crops).

Pinch off or top the growing point of the plant about 6–8 weeks before harvest is to be discontinued (2 weeks earlier for the fall crop). This transfers the sugars and energy normally used to produce new flowers and leaves to other components of the plant, namely the fruit, causing them to enlarge and ripen early.

Cluster Pruning

As most modern tomato cultivars set fruit readily, all flowers on a truss may set fruit. The time frame between setting of the first flower and the last may be 4–10 days, resulting in fruit size gradient reflected at harvest time. To ensure uniform size and rapid harvest, prune each cluster to 4 fruits. Prune once the first 4 flowers are properly set, by pinching off the remainder of the flower truss. Under good light conditions, with a strong vigorous variety or a fall crop, it may be necessary to leave 5 fruits/cluster up to the 3rd cluster after which 4 fruits/cluster are left. Adjust the number of fruits/cluster and the number of clusters at 5 fruits/cluster depending on available light and plant vigour. This decision must be carefully considered as too much fruit load on the lower clusters severely restricts later production. Truss supports may be necessary to prevent the fruit truss from kinking [*Plates* 15 and 16].

Pollination

Pollination is necessary for normal fruit set to occur. Pollen from the anthers must reach the ovaries at the base of the flower for fertilization and fruit development to occur. The number of seed developed determines fruit size, quality and shape. Tomato flowers are self-pollinating, but to ensure high quality uniform tomatoes, use electric bees, buzzers, or bumblebees to increase pollination [*Plate* 17].

Successful pollination involves:

- production of viable pollen
- release of the pollen from the anthers to the stigma
- germination of the pollen grains on the stigma
- growth of the pollen tubes down the stigma resulting in fertilization (fruit set).

Adverse temperatures, light and nutritional conditions cause some, if not all, of these processes to fail, resulting in poor fruit set and poor fruit quality. Day temperature should not fall below 18°C or exceed 30°C once flowering starts.

Bumblebees

Bumblebees are commonly used today to pollinate tomato crops to produce high quality fruit. Introduce bumblebee hives (2–3 hives/ha) into a tomato greenhouse once the first cluster is fully opened. When bumblebee workers visit the flowers to obtain pollen, many pollen grains are disturbed from the stamens landing on the stigma, initiating pollination. The bumblebees visit flowers when pollen is available (mid morning to early afternoon), and visit the same flower several times over the bloom period.

As the plant grows and more flowers open, add extra hives (4–5 hives/ha as determined by the bumblebee supplier). As the hive ages, the worker bumblebee population declines and the social order of the hive changes, resulting in an inefficient hive. Hives lose their pollination efficiency after 6–8 weeks. At this time, replace the hives or bring more hives in to maintain good pollination. This is repeated throughout the growing season.

A brown discoloration or marking of the cone/trumpet of the flower indicates if a bumblebee has visited the flower. Monitoring these marks determines whether the bumblebees are performing well [*Plate* 18].

Place hives in a convenient location on a sturdy stand or shelf — 1.0–1.5 m high in a shaded area or provide a shade cover to prevent overheating in the summer. The hives must be located away from vibration or drafts to ensure proper functioning. Hives placed in a cool location are slower to develop adequate adult worker bumblebees to efficiently pollinate the crop.

Modern hives are designed to provide a carbohydrate source for the bumblebees, requiring little or no maintenance by the operator. Hives are also equipped with a one-way opening that, when in operation, only allows the bumblebees to enter the hive, not exit. This is necessary to capture all the bumblebees when the hives are being removed if and when chemical sprays are applied to the tomato crop. Bumblebees are sensitive to various

chemicals. Once chemicals are introduced into the hives, or brood, they cause the hive to deteriorate, resulting in poor pollination. Thus, a good biological control program against pests is necessary to obtain full benefit of bumblebee pollination.

While bumblebees will exit greenhouses through vents, they usually return. However, if the outside temperature is low, or the vents close before the bumblebees return, these bumblebees will die, especially in February and March. This can be a problem in gutter vented double poly greenhouses, where the light quality through the vent opening appears different from that through the double poly — attracting the bees, causing them to go outside. Under cool temperatures, the bumblebees die, decreasing hive size and pollination activity. This can be rectified by:

- changing the poly covering to one that has smaller light transmission difference
- decreasing vent opening by installing end wall fans to assist in early venting
- installing bee screens at the gutter vent to prevent escapes.

In small tomato greenhouses, bumblebee pollination may not be effective. The number of bumblebees in an average mature hive can be as high as 300 adult bees. When the demand for pollen is very high, excessive visits to each flower can cause damage to the flower and in extreme cases, flower abortion. Thus, hand pollination with the use of electric bees must be conducted.

During late fall, winter and early spring, flowers of most cultivars grow with a slightly different shape, and natural pollination becomes more difficult. This is a result of low light and temperature, and is occasionally aggravated by high nitrogen. The optimum time for pollination is between 11 a.m. and 3 p.m. when flowers are dry and pollen is shedding. Other methods, such as tapping the overhead wires or the string supporting the plants, and coarse water sprays have not generally been satisfactory. Backpack air blowers similar to leaf blowers can also be used to pollinate the flowers. Fruit quality problems related to inadequate pollination are invariably the result of poor and uneven seed set, which causes hollow, misshapen fruit.

Climate

Air temperature has a profound effect on growth and flower development, fruit setting, development, ripening and quality. The 24-hr average temperature affects the speed or rate of growth. The higher the 24-hr average temperature, the faster the growth. A tomato crop achieves its maximum growth at 25°C day and night temperature, but maximum fruit production is achieved at 18°C night and 20°C day or a 24-hr average of 19°C. The day-night temperature differential determines the morphology of the plant (i.e. its shape) and the degree of vegetativeness or fruitfulness.

TABLE 6–1. Recommended Air Temperatures (°C) for Tomatoes

	Low Light	High Light	With CO_2
night minimum	17	18	18
day minimum	19	21	21
ventilation	21	24	26

Note 1: During very bright weather, temperatures higher than 26°C will not harm the plants, but above 29°C the blossoms will be injured on most cultivars.
Note 2: A minimum media temperature of 16°C is recommended (optimum 18°C–21°C).

Adjust temperatures based on available light to maintain high rate of growth, with large fruit of high quality. Under lower light conditions (early winter or cloudy days) maintain a lower 24-hr average temperature that is then increased when the light level increases. Adjust the day-night temperature difference to maintain plant vigour and fruit size. A large day-night temperature differential shifts the plant to a more generative phase (more flowers, thinner head, larger fruit size) while a low or no temperature differential results in a more vegetative plant (less flowers, thicker head).

Light is also a critical component of tomato production during the winter. Under winter low-light conditions, the plant tends to have long internodes, reduced flower bud development and clusters that fail to set fruit. These problems are minimized by decreasing the rate of growth through a combination of one of the following production practices:

- by lowering 24-hr average temperature
- lowering the volume of water applied
- raising EC of the nutrient solution and the root zone media
- lowering the RH (higher VPD).

Whitewash applied to the exterior greenhouse covering reduces both the light intensity and temperature during the summer inside the greenhouse. This enhances a stronger head, improves flower quality and fruit set, as well as decreases fruit quality problems associated with high surface temperatures of the fruit.

The tomato crop can withstand a wide range of relative humidity as long as the RH does not fluctuate drastically over a short period. At low RH (high VPD), water supply to the crop is critical; while at high RH (low VPD), incidence of diseases can increase. High relative humidity (low VPD) during the day can improve fruit setting. A low RH (a high VPD) results in poor pollination and fruit set. Ideally keep a relative humidity of 75%–85% or a VPD of 0.4–0.8 kPa.

To alter plant vigour or appearance, change the RH or VPD. For example, under low RH or high VPD, the plant tends to have a thinner head and leaves. At higher RH or low VPD, the plant tends to have thicker leaves and heads, flowers with extended trusses or stems that are more prone to kinking or bending, resulting in poor fruit quality (size and shape).

Carbon dioxide supplementation benefits the tomato crop at all stages during the winter (no ventilation). During sunny days, apply a minimum CO_2 concentration of 1,000 ppm, and 400 ppm CO_2 when vents are opened more than 10%. Under low light conditions (40 watts/m^2), 400 ppm is ideal. In summer (with ventilation) it is economical and has become popular to apply supplemental CO_2 at a concentration of up to 400 ppm (especially early in the day and late evening before sunset).

Horizontal airflow (HAF) fans help minimize temperature gradients in the greenhouse, and uniformly distribute CO_2 throughout the canopy. An air speed of 1 m/sec. is recommended. HAF fans must be turned off during the dehumidification cycle to efficiently dehumidify the greenhouse. The convectional currents created by the heating system are disrupted by the horizontal airflow, preventing the warm, moist air from easily escaping through the vents. Table 6–2, p. 55, is a summary of growing recommendations for tomatoes.

Nutritional Requirements

Sustained fruit production is accomplished only under optimum environmental conditions and by timely applications of water and nutrients. A well-balanced plant is judged by its thick stem, dark green leaves and its closely spaced, large, readily-setting flower clusters. A properly nourished plant should have a 1 cm thick stem at a point 15 cm below the growing tip. Thicker stems indicate excessive vegetative growth and are usually associated with poor fruit set and low productivity. Thinner stems usually indicate carbohydrate starvation, slow growth and ultimately, low overall productivity.

A mature tomato crop uses 2–3 L of water per plant per day when light levels are high (average summer day). A complete nutrient solution must be applied at all times to sustain the growth and fruit development necessary to obtain high production of good quality tomatoes. The fertilizer schedule, Table 6–3, p. 55, is adjusted based upon the stage of the crop.

Tomato plants have different absorption rates (especially nitrogen and potassium) at various stages of growth. The nitrogen absorption by the tomato plant during the first 2–3 flower trusses is about the same as potassium. But as the fruit load increases so does the potassium uptake, resulting in 2:1 potassium:nitrogen uptake. An excessive amount of nitrogen under low light conditions early in the production cycle results in an overly vegetative plant prone to disease, poor flower development, fruit set and size. Lower nitrogen feed during this phase helps control plant growth. (Note: other factors can also strongly influence plant growth and must be considered at the same time.)

The volume and timing of the nutrient solution applied through fertigation is critical in rockwool culture, and greatly affects fruit quality. Begin fertigation 1–2 hr after sunrise and end 1–2 hr before sunset. This helps decrease incidence of two physiological disorders, russetting and fruit cracking in the summer, as well as diseases. Night watering may be needed during the winter months when heating systems are fully operational and the RH in the greenhouse is low, or during the summer when light intensity and temperatures during the day in the greenhouse are high.

Fertilizer application is very critical and greatly influences the growth and development of the crop, and subsequently the quantity and quality of the fruit. The average uptake of the major nutrients by a tomato crop is estimated as follows:

nitrogen	370 kg/ha
phosphorus	50 kg/ha
potassium	680 kg/ha
magnesium	290 kg/ha
calcium	450 kg/ha

Regulating the supply of water and nitrogen is the most common and effective technique used to control crop growth. Infrequent irrigation and low volume, low relative humidity and high EC in the irrigation water result in hard plants and slower growth. Regulation of EC is the preferred method of slowing growth because it is simple, effective and dependable. Nitrogen (N) supply can also be regulated directly by adjusting the N fertilization, or indirectly by varying the supply of other nutrients, such as potassium (K). A high K:N ratio in the fertilizer solution is a frequently used technique to slow growth.

Nitrogen (N)

This nutrient has the greatest impact on vegetative growth. High rates of N induce vigorous vegetative growth to the detriment of fruit production. However, under hot and bright conditions, the N level must be increased to enable the plant to continue growing and to maximize its fruit production potential.

Strong thick stems, curled leaves in the head of the plant, big flower trusses and individual flowers, mark an excess of N with poor fruit set. Symptoms of N deficiency are hard plants with thin heads, light green foliage and pale yellow flowers.

Potassium (K)

Potassium has a great influence on fruit quality and at high rates is also effective in hardening growth. Potassium levels are particularly critical at planting time for subsequent growth control and preventing ripening disorders. The ratio between potassium and nitrogen is also important in growth control. The higher the ratio, the slower the growth. Fruit quality problems such as blotchy ripening, boxy fruit and green-back (to some extent) are associated with low levels of K.

Phosphorus (P)

Phosphorus is used in much smaller quantities than N and K. Initially, phosphorus is important for early root growth, and is strongly influenced by the temperature and pH of the growing media. At low temperatures P uptake decreases, and at high pH it is not readily available for plant uptake. It has a profound effect on both vegetative growth and fruit set. Deficiency symptoms include a characteristic purple colour of the leaf veins and the stem, thin growth and poor cluster development. Phosphorus toxicity is uncommon.

Magnesium (Mg)

Although magnesium deficiency is very common, it rarely results in yield reduction; it may affect fruit quality. Deficiency usually exists only in the plant and is related to high K feeds or poor root development, both of which make it difficult for the plant to take up sufficient magnesium. The plant is then forced to move magnesium from the old to the new leaves. A magnesium deficiency (chlorotic older leaves) is easily corrected with Epsom salt sprays.

Calcium (Ca)

Calcium deficiency usually causes blossom end rot of the fruit and dieback of the growing tips. In most cases, Ca deficiency is caused by water stress because of inadequate or uneven watering, frequent and large variations in relative humidity, imbalanced fertilizer program or high salts. Sprays of calcium nitrate or calcium chloride help correct a Ca deficiency, but improving water balance in the plant is a more practical solution to the problem.

Sulfur (S)

Sulfur is rarely a problem since it is present in many fertilizers as a carrying element. However, high sulfur levels can become a source of excessively high salts and can also adversely affect the uptake of molybdenum.

Iron (Fe)

Iron deficiency, a frequent problem, is usually observed as chlorosis of young leaves. In most cases, iron deficiencies are induced. The indirect causes of iron deficiency can be high media pH, too high a manganese level, poor root growth or anaerobic conditions due to over watering. Foliar sprays of iron salts or iron chelates are helpful, but the best solution is to eliminate the source of the problem.

Manganese (Mn)

Manganese deficiency is frequently confused with iron deficiency. Symptoms are interveinal chlorosis, that becomes more yellow as the deficiency progresses and light green coloured veins. As the deficiency symptoms become more severe, brown spots appear at the base of the leaflets. However, in most instances, it is an expression of iron toxicity. Manganese toxicity can be a problem and is encountered when media, especially soil, is excessively steamed and not followed by leaching.

Copper (Cu)

Copper may occasionally be deficient in peat media or in soilless culture if it is omitted in the fertilizer schedule. Symptoms are similar to high salts, with dark-green younger leaves that frequently wilt. As symptoms progress, the leaflet tips become necrotic and flower buds fail to develop.

Boron (B)

Boron deficiency symptoms include brittleness of leaves, premature wilting and in severe incidences, dieback of the growing tips. This deficiency is easily corrected with foliar sprays of a borax solution. The rate of application is important since boron toxicity can cause severe plant damage.

Zinc (Zn)

This element is rarely deficient. Toxicity is a potential problem in recirculating hydroponic systems when galvanized piping is used. The nutrient solution reacts with the piping, releasing excessive quantities of Zn. Also, rainwater collected from newly erected greenhouses where the galvanized gutters have had no special treatments can cause Zn problems.

Molybdenum (Mo)

Low pH conditions, or high sulfur levels can induce molybdenum deficiency. Although symptoms of molybdenum deficiency are not easily identifiable, leaf tissue analysis is a dependable diagnostic tool.

Harvesting and Storage

Harvest greenhouse tomato fruit with the calyx attached to the fruit to help identify the product. Harvest 3 times a week or every other day, especially during the summer. This ensures all fruit is harvested at about the same stage of ripeness. Harvest fruit when they are turning from green to orange-red in colour. Some growers may harvest at the breaker stage (blossom end of the fruit starting to show colour). Tomato fruit harvested at a more advanced stage of ripening has greater flavour, but may not have as long a shelf life as it becomes over-ripe more quickly.

Harvest manually by snapping or breaking the calyx at the knuckle (a natural break point on the flower stem). Place fruit in picking baskets or crates to prevent punctures by the calyx. Clip the stem if necessary to minimize fruit punctures when handled during packing and at display counters. Fruit that is dropped will easily bruise, resulting in decreased shelf life.

Pick tomatoes as early as possible in the morning while it is still cool. Move fruit quickly to a covered area or directly to a cooler. Fruit left in the greenhouse rapidly overheats and deteriorates. Ideally, cool fruit to 12°C (53°F) as quickly as possible. The packing facilities must be cooled (15°C) to maintain fruit quality and, if required, store fruit at 12°C after grading and packing before shipping in cooled trucks to the marketplace. Computerized, colour sorters with weight and size grading packing lines are commonly used to pack tomatoes. Pack uniformity (colour, size and quality) is critical to ensure good acceptance at the marketplace. Label all tomato fruit with a PLU or bar coding sticker during packing.

After removing the fruit from cold storage, take care to avoid condensation on the fruit by either moving it into a dry atmosphere or by raising the fruit temperature gradually.

Contact the Ontario Greenhouse Vegetable Growers, Box 417, Leamington, Ontario N8H 3W5, telephone: (519) 326–2604 for updated fruit grade specifications and price structuring according to fruit grade.

TABLE 6–2. TOMATO: Summary of Growing Recommendations

	Germination	Plant Raising	Transplanting	Harvesting Stage	Full Harvest
Temperature**					
day °C	25°C	19°C–21°C	24°C	19°C	20°C–22°C
night °C	25°C	19°C–21°C	24°C	19°C	17°C–19°C
EC (mS/cm)	0.0–1.0	2.5–3.0	2.5–3.0	2.7–3.5	2.7–4.0
pH	5.8	5.8	5.8	5.8	5.8
Vol. of feed (L/day)*		0.2–0.3	0.2–0.3	0.5–1.5	1.5–2.5
Fertilizer Schedule		A	B	C	D

* as required (watering strategies)
**use lower settings when light level is low

TABLE 6–3. Fertigation Schedule for Tomato (ppm nutrient)

	N	NH_4	P	K	Ca	Mg	Fe	Mn	Zn	B	Cu	Mo	S*	Cl*	HCO_3
A. Slab Saturation	200	10	50	353	247	75	0.8	0.55	0.33	0.5	0.05	0.05	120–200	100–125	25
B. 4–6 wks after planting	180	10	50	400	190	75	0.8	0.55	0.33	0.5	0.05	0.05	120–200	100–125	25
C. Normal Feed	190	22	50	400	190	65	0.8	0.55	0.33	0.5	0.05	0.05	120–200	100–125	25
D. Heavy Fruit Load	210	22	50	420	190	75	0.8	0.55	0.33	0.5	0.05	0.05	120–200	100–125	25

* The fertilizers selected to create the nutrient solution will determine the final level of these anions.

	Kg/1,000 L (Dilute 1:100)			
Fertilizer	**A**	**B**	**C**	**D**
Calcium nitrate	112	82.1	82.1	82.1
Potassium nitrate	25.72	42.4	40.89	56.27
Monopotassium phosphate	6.75	6.75	6.75	6.75
Potassium sulphate	45.11	38.08	39.21	31.81
Potassium chloride	3.75	3.75	3.75	3.75
Magnesium sulphate	66.0	66.0	56.0	66.0
Ammonium nitrate	0.0	4.0	8.0	8.0
	g/1,000 L (Dilute 1:100)			
Iron chelate 13%	615.38	615.38	615.38	615.38
Manganese sulphate	207.69	207.69	207.69	207.69
Zinc sulphate	94.29	94.29	94.29	94.29
Borax	326.67	326.67	326.67	326.67
Copper sulphate	16.0	16.0	16.0	16.0
Sodium molybdate	10.87	10.87	10.87	10.87
Desired EC (mS/cm)	2.5–3.0	3.5	3.0–4.0	2.5–3.5
Desired pH	5.8	5.8	5.8	5.8
Vol of Water (L)**	0.25–0.5	0.5–1.0	1.0–2.0	1.5–2.5

** As required (watering strategies).

7. Cucumber Crop

The success of cucumber production in the greenhouse depends upon one's ability to maintain ideal conditions for growth. Cucumber plants are extremely sensitive to change. Optimizing the greenhouse environment including light, temperature, humidity, air movement and the root environment (i.e., root temperature, moisture availability, nutrition, etc.) produces high yield and quality. A tropical plant originating from the Indian subcontinent, the cucumber plant performs best when grown under high light, temperature, humidity, moisture and fertility conditions.

English cucumber is the principal commercial cucumber grown in the greenhouse. These seedless cucumbers are parthenocarpic, with flowers that do not require pollination for fruit formation. There is an increase in Ontario production of mini cucumbers, grown specifically for the niche market.

Cucumber plants grow rapidly, and depending on light and growing conditions, produce marketable fruit in 8–12 weeks. Cropping cycles are:

- a 2-crop cycle with a January planting, mid-February harvest and termination in mid-July or August, followed by an August planting, end of September harvest and termination end of November/beginning of December or
- a 3-crop production cycle to maintain high fruit quality and market share consisting of a December planting with late-January to early-February harvest and termination in May, followed immediately with a 2nd planting that terminates in August. The 3rd planting, started immediately after clean-up, is terminated in December.

The planting and termination dates are adjusted based on the marketing schedule and light availability. In the past, producing cucumbers during November, December and January has been successful when prices have been traditionally higher. However, recent increases in imported seedless cucumbers has dropped the price, lowering returns. Given the high cost of fixtures and electricity, supplementary light is not financially worthwhile.

Cultivars

There is a wide selection of cultivars suitable for Ontario greenhouse growing conditions. Fruit quality, yield and plant habit vary between cultivars and seed companies. With the marketplace demanding fruit 32–42 cm long and a diameter of 4 cm, a suitable cultivar should provide a higher percentage of medium-large fruit. There are lower returns on short cucumbers.

The use of the PMT (Powdery Mildew Tolerant) cultivars is increasing, and each seed company has a selection that may be suitable to the Ontario grower. PMT or resistant cultivars have a slightly lower yield, making it more difficult to grow them economically. Earlier PMT cultivars produced shorter cucumbers, but the new cultivars are longer. There are also some operations growing the mini-cucumbers or gherkin-type cucumbers for specific markets.

Contact your OMAF greenhouse vegetable specialist, the OMAF web site or your seed supplier for more details on the individual cultivars.

Seeding

Seed may be sown directly into rockwool blocks or in flats filled with vermiculite. After emergence, transplant the seedlings from the vermiculite flats into rockwool blocks. Cucumber seed germination is rapid and must be treated accordingly. The optimum seed germination temperature for cucumbers is 26°C–28°C.

Cucumber seedlings emerge 2–3 days after sowing and if sown in flats are ready for transplanting into blocks in 4–6 days.

Plant Raising

After transplanting, maintain a temperature of 23°C–25°C day/night to rapidly establish roots. Subsequently, lower the temperature to 23°C day and 21°C night, with the day temperature based on light intensity. At higher light intensities, a 2°C increase is beneficial. To avoid impeding root development it is very important to maintain the block temperature between 21°C–23°C. A too wet or too dry a rockwool block also impedes root development.

To maximize space efficiency, initially place the blocks close together; increase the spacing when the leaves begin to touch. This increases light interception and helps maintain a sturdy, stocky plant. Supplementary lighting with HPS lamps at 20 watts/m^2 for 24 hr improves plant quality and reduces the time required to produce a plant suitable for transplanting. Supplemental CO_2 (1,000 ppm on sunny days, 400 ppm on cloudy days or when using supplementary lights) helps achieve the desired plant in a shorter time.

A cucumber plant is ready for transplanting into the production houses when:

- 4–5 leaves have developed
- is about 25–30 cm tall and
- weighs about 25–40 g.

To obtain a plant of this size it must be staked [*Plate* 19]. Place a stake in the pot beside the plant. Use elastic bands or metal rings to hold the plants to the stake. At transplanting time the staked plants will be less prone to damage during transport and will be easier to string up after planting in the greenhouse.

Plants can be moved into the production greenhouses earlier (3–4 leaf stage). Place the plants beside the opening in the rockwool bag and water the plants with the drip irrigation system. The advantage of moving the plants earlier include:

- decreasing the time required in the starter house
- allowing the use of smaller starter houses.

However, the younger plants placed directly in the greenhouse require greater care to ensure proper root zone temperature and adequate moisture. Once they reach an adequate size, they may be moved onto the opening, allowing roots to develop into the slab.

Plant Spacing

In general, space plants at 0.55–0.74 m^2/plant (6–8 $ft.^2$/plant) or 1.4–1.8 plants/m^2. The larger spacing per plant:

- improves fruit quality, length, colour
- decreases costs, number of seeds, blocks, growing media, labour
- maintains a high yield (number of cucumbers/plant or cucumbers/m^2).

In general, grow cucumber plants in twin growing rows with a walkway between each row. Locate the heating pipes on the walkway for a hot water heating system and within the twin rows for a steam heating system. Make the walkways 140–170 cm wide and the space between the twin rows 100–120 cm. Plant spacing along the growing row varies, depending on the growing system used to achieve the plant population desired.

Growing Media

Rockwool is the media most commonly used in Ontario for cucumber production. A cucumber slab measures 20 cm wide × 7.5 cm high × 90–100 cm long. With a 90 cm long slab, use 2 plants/slab; with a 100 cm long slab use 3 plants/slab. Space the slabs within the rows to provide the desired plant density. Using 3 plants/bag requires less rockwool.

To spend even less on rockwool, consider using the V system to grow plants. Use a single growing row where the plants from the single row are trained to form 2 rows of stems at the appropriate stem spacing (1.35–1.81 stems/m^2). This system lends itself well to recirculating the nutrient solution.

After placing the rockwool slabs, soak the bags at an EC of 2.0–2.5 mS/cm and a pH of 5.8 (*Rockwool Culture*, p. 33). Immediately after planting, irrigate the crop with a complete nutrient solution (EC 2.0 mS/cm and a pH of 5.5) of sufficient volume to fully saturate the slabs. Cut the bags to allow the excess solution to drain (completed after planting). Depending on light conditions, do not water for 2–3 days; then water according to plant requirements. Use a nutrient solution containing a higher calcium level from planting out until plants reach the wire (Table 7–4, *Summary of Fertilizer Schedule for Cucumbers*, p. 62).

Crop Training

The modified umbrella system is commonly used in Ontario. Plants are trained along a twine attached at the base of the plant and the overhead wire (1.9–2.0 m high). Once the plants reach the wire, there are two options.

1. Remove the growing point of the plant, allowing 1 leaf to remain over the wire. Develop two laterals 1–2 nodes below the wire. Attach them to the overhead wire via special hooks or by wrapping around the wire. After the laterals with about 3–4 nodes are trained along the wire, let them grow down; remove the growing point when the lateral is approximately halfway to the ground. Then, allow another lateral at the wire to develop and train in a similar fashion. After harvesting all the fruit from the first lateral, remove to make room for the next lateral to develop. Repeat this process throughout the growing season (Figure 7–1, *Cucumber Pruning System 1*).

OR

2. Train the main stem along the wire until it reaches the neighbouring plant when the growing point is pinched off. At the 2nd and 4th nodes from the bend, allow the laterals to develop. Have these laterals hang down; pinch off when they are half way to the ground. Then develop the next set of laterals to develop off the main stem along the wire. Repeat this process throughout the growing season (Figure 7–2, *Cucumber Pruning System 2*).

FIGURE 7–1. Cucumber Pruning System 1

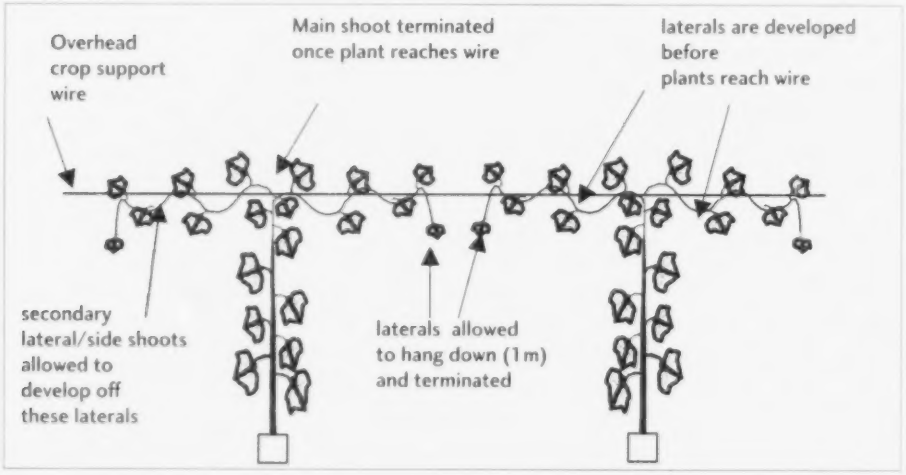
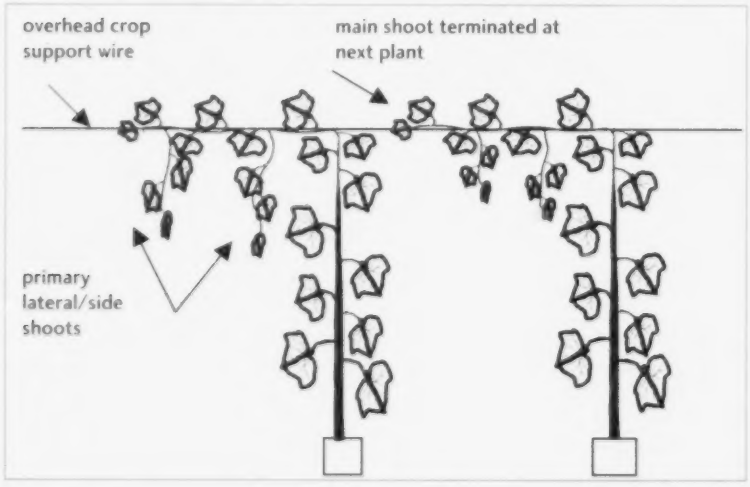

Overhead crop support wire
Main shoot terminated once plant reaches wire
laterals are developed before plants reach wire
secondary lateral/side shoots allowed to develop off these laterals
laterals allowed to hang down (1 m) and terminated

FIGURE 7–2. Cucumber Pruning System 2



Once the basic framework is achieved, subsequent pruning depends upon the vigour of the plants. For good fruit colour make sure there is good light penetration. To achieve this, it may be necessary to:

- remove 1 or 2 healthy green leaves in a vegetative crop
- train laterals to grow downwards.

During the season remove the senescing (aging or drying out) leaves above the wire. Train a lateral over and along the wire so that it receives good light. Fruit development and further lateral growth from this overhead lateral will continue to produce fruit during the remainder of the season.

Fruit Pruning

Fruit pruning is necessary to ensure a proper balance between the number of leaves produced and the number of developing fruit. If the plant is too vegetative (i.e., too many leaves), fruit set and harvest is delayed. If the plant is too fruitful, future cucumber production is jeopardized. A balanced plant maintains a steady production throughout the season, minimizing weekly periods of high production followed by low production the following week. In a fruitful crop, where there is too much fruit in relation to leaf area, young fruit take longer to mature, become crooked or abort. This restricts new flower development and growth. Use Table 7–1, *Fruit Load on Young Cucumber Plants* as a guide to balance the young cucumber plant.

On the main stem, only allow 1 fruit per alternate node to develop at all times. On the laterals, allow 1 fruit per node to develop.

TABLE 7–1. Fruit Load on Young Cucumber Plants

	Ht of 1st fruit set or # leaves before 1st fruit	# fruit to wire (2 m)
Winter planting (Dec., Jan., Feb.)	90–100 cm OR 10–12 leaves	3–4
Spring/fall planting (Apr., May, June)	80–90 cm OR 8–10 leaves	5–8
Late fall (Oct., Nov.)	90–100 cm OR 10–12 leaves	3–4

Climate

Temperature strongly influences the rate of development, fruit length, colour and the balance between vegetative growth and fruit development (generative growth) of seedless cucumbers. Adjusting the 24-hr average temperature determines the rate of growth or speed of growth. The optimum 24-hr temperature for cucumbers is 21°C. Varying the day and night temperature influences the plant morphology and alters the vegetative: generative balance, that is leaves:fruit balance (*Temperature Control* p. 19).

In general, use an initial high 24-hr average temperature (day and night temperatures close together) to rapidly establish the plant and reach the overhead wire. This creates plants with thinner stems, longer internodes and widely spaced, slightly thinner and smaller leaves. Subsequently lower the night temperature to encourage development of thicker laterals and strong flowers. Plant appearance determines the level and duration of the temperature drop. Use a lower temperature for a longer time to thicken the growing stem and leaves, and a higher temperature to thin it (Table 7–2, *Temperature Regime for Cucumber Production*, p. 61).

To minimize water condensation on the fruit, gradually raise the air temperature at the end of the night. Raise the temperature 1°C/hr, with the day set temperature achieved at least ½ hr before sunrise. Sharp changes in temperature result in dramatic changes in relative humidity (RH) or vapour pressure deficit (VPD).

Do not try to quickly lower the temperature or relative humidity with a sharp increase in venting. The fruit may suffer from chilling injury, curl or abort. A VPD between 0.4–0.8 kPa minimizes the chance of condensation and maintains an actively transpiring plant.

Cucumber plants grow rapidly and may use up to 3–4 L of water per plant per day, especially a mature, fruit bearing plant in the summer. Apply a complete nutrient solution at all times. In rockwool culture, there may be as many as 30 irrigation cycles in a day. See Table 7–4, p. 62 for a suggested fertilizer schedule for greenhouse cucumber production.

The concentration of fertilizer applied (EC) and the amount of water applied varies with:

- the time of the year
- size of the plant
- prevailing greenhouse environmental conditions.

Applying a higher EC solution increases fruit quality and shelf-life. Avoid excessive application of the nutrient solution to the root zone because saturation of the media increases the incidences of Pythium root rots. Start watering 1–2 hr after sunrise and terminate 1–2 hr before sunset. This allows aeration of the root zone to occur during the night. Night watering may be necessary on cold winter nights when the demand for heat is high and the greenhouse RH is low, or on extremely sunny, dry days in the spring and summer. Overwatering of a crop produces soft stem growth prone to diseases such as *Botrytis*, gummy stem blight, or *Penicillium*. See Table 7–3, *CUCUMBERS: Summary of Growing Recommendations*, p. 62 for a summary of growing recommendations.

TABLE 7–2. Temperature Regime for Cucumber Production

	Day	Night	Vent
After Transplanting (3–4 days)	23–25°C	23–25°C	None
Growth to wire (3 wks)	23–25°C	21–23°C	+2°C
Until first lateral harvested/picked	23°C	21°C	+2°C
Remainder of season*	23°C	17–21°C	+2°C

* This variation in night temperature is suggested to alter plant growth. The warmer night will result in thinner plants, rapid fruit development; the cooler night will result in a thicker plant, strong lateral growth and flower development, and slower plant growth.

Harvesting and Storage

Cucumber fruit matures from flower to harvesting size in 10–14 days, depending on factors such as cultivar, light, temperature, moisture and nutrition.

Minimum marketable length is 28 cm with a 4 cm minimum diameter. Cut, not twist, fruit from the plant. A clean cut of the fruit stalk allows for rapid healing of the wound, and decreases the risk of disease.

To prevent fruit from becoming over-mature, harvest cucumbers every other day. Daily harvest may be necessary in some weeks in the summer when fruit growth is rapid. Traditionally, cucumbers are harvested 3 times per week.

Seedless cucumbers have a skin that provides little resistance to desiccation. They lose water very rapidly. Shrink-wrapping the fruit extends the shelf-life and allows attaching of PLU or bar coding labels. Contact the Ontario Greenhouse Vegetable Growers (OGVG) regarding grade specifications and label requirements.

Store cucumbers at 13°C away from drafts. The fruit is extremely sensitive to ethylene — 0.5 ppm of ethylene causes cucumbers to yellow. Do not place cucumbers in storage facilities or transport with ethylene-producing fruit such as apples or tomatoes, etc.

TABLE 7-3. CUCUMBERS: Summary of Growing Recommendations

	Germination	Plant Raising	Transplanting	Harvesting Stage	Full Harvest
Temperature ( )**					
day °C	27°C–28°C	24°C	23°C–25°C	23°C	23°C
night °C	27°C–28°C	21°C	23°C–25°C	21°C	21°C–17°C
EC (mS/Cm)	0–1.0	1.0–2.5	2.0–2.5	2.5–3.0	2.1–2.8
pH		5.8	5.8	5.8	5.8
Vol. of feed (L/day)*		0.2–0.3	0.2–0.3	1.0–1.5	1.5–2.5
Feed Schedule		A	B	C	D

*as required (watering strategies)
** use lower settings when light is low

TABLE 7-4. Fertigation Schedule for Cucumber (ppm nutrient)

	N	NH_4	P	K	Ca	Mg	Fe	Mn	Zn	B	Cu	Mo	S*	Cl*	HCO_3
A. Slab Saturation	200	10	50	253	247	75	0.8	0.55	0.33	0.5	0.05	0.05	120	0	25
B. For 4–6 wks after planting	180	10	50	370	210	75	0.8	0.55	0.33	0.5	0.05	0.05	120	0	25
C. Normal Feed	190	22	50	370	190	65	0.8	0.55	0.33	0.5	0.05	0.05	120	0	25
D. Heavy Fruit Load	210	22	50	370	190	75	0.8	0.55	0.33	0.5	0.05	0.05	120	0	25

* The fertilizers selected to create the nutrient solution will determine the final level of these anions.

	Kg/1,000 L Dilute 1:100			
Fertilizer	**A**	**B**	**C**	**D**
Calcium nitrate	112.11	92.67	82.11	82.11
Potassium nitrate	25.72	31.5	40.89	56.27
Monopotassium phosphate	6.75	6.75	6.75	6.75
Potassium sulphate	25.77	44.05	37.19	25.95
Magnesium sulphate	66.0	66.0	66.0	66.0
Ammonium nitrate	0.0	4.0	8.0	8.0
	g/1,000 L (Dilute 1:100)			
Iron chelate 13%	407.69	407.69	407.69	407.69
Manganese sulphate	165.38	165.38	165.38	165.38
Zinc sulphate	91.43	91.43	91.43	91.43
Borax	246.67	246.67	246.67	246.67
Copper sulphate	16.0	16.0	16.0	16.0
Sodium molybdate	10.87	10.87	10.87	10.87
Desired EC (mS/cm)	2.5–3.0	2.5–3.0	2.0–3.0	2.5–3.5
Desired pH	5.8	5.8	5.8	5.8
Vol of Water (L)	0.25–0.5	0.5–1.0	2.0–3.0	2.0–3.0

8. Pepper Crop

Greenhouse-grown sweet peppers are increasing in popularity with the Ontario consumer, providing an alternative to tomatoes and cucumbers. Fully matured, red-, yellow- or orange-coloured fruit are harvested, but other colours such as purple or green are also grown.

Cultivars

Select cultivars based on yield potential, fruit size, shape and quality, plant habit, vigour, colour desired by the marketplace and disease tolerance, especially to viruses. The most commonly grown cultivar is the large, blocky, mainly red, pepper.

Contact your OMAF greenhouse vegetable specialist, your seed company or the OMAF web site for more details on cultivars.

Crop Schedule

Since peppers are very slow growing, use a year-round greenhouse pepper schedule. Typically, sow seeds in early October, transplant into the greenhouse in early December and harvest the first fruit beginning mid-March and ending late November/early December.

TABLE 8–1. Pepper Crop Schedule

Crop Type	Sow	Plant	Harvest	Terminate
all year	1st wk. Oct.	1st wk. Dec.	mid-end Mar.	1st wk. Dec.

Overwinter production of pepper for harvesting during December, January and February, without supplementing lighting is not recommended as ambient light levels are too low to sustain an economic yield. At this time, supplemental high-pressure sodium lighting is not being used in Ontario to sustain yields.

Plant Propagation

Sowing

Use seed of high quality from a reputable seed company. Sow the seed in rockwool plugs. Prior to sowing, thoroughly soak these plugs with either plain water or a complete nutrient solution at pH 5.8 and EC 1.0 mS/cm. After sowing, cover the rockwool plugs with medium vermiculite, soak, then cover with a 2-mil clear poly sheet and place on benches with bottom heat, or in germination chambers. The optimum germination temperature is 25°C–26°C. Once emergence occurs (after 3–4 days), remove from the germination chamber or remove the poly coverings, and reduce the temperature to 23°C. Transplant the seedlings once the cotyledon leaves are fully expanded and the true leaves have begun to emerge (approximately 14–18 days after sowing).

Plant Raising

After the rockwool blocks (10 × 10 × 7.5 cm) are soaked with a complete nutrient solution (EC 1.5–2.0 mS/cm; pH 5.2), place the seedlings directly (straight up or bent at 90° as a hockey stick) into the hole and put vermiculite at the base of the stem to provide support. More operations now use the hockey stick technique to increase stability of the plant in the rockwood block.

Initially, place the blocks close together to conserve space. As the young plants grow, space the blocks further apart to a final spacing of 18 plants/m^2 prior to transplanting into the greenhouse. During this phase, the optimum night temperature is 20°C with a day temperature of 21°C–23°C. Adjust these temperatures based on available light and the desired growth. Apply a complete nutrient solution to the transplants as necessary. The amount of solution and frequency of application is determined by the temperature, available light, greenhouse conditions and plant size.

Carbon dioxide supplementation (700–800 ppm) and supplementary high pressure sodium lighting at 20 watts/m^2 greatly improves transplant vigour and size, as well as decreases the time required (1–2 weeks) to attain an ideal transplant. Pepper plants are ready for transplanting when the first flower bud (king flower) is clearly visible or about to open at the first branch on the pepper plant, which usually occurs 6–8 weeks after sowing [*Plate* 20].

Plant Spacing

A plant density of 3 plants/m^2 is optimal because plants are normally trained as a 2-stemmed plant, resulting in 6 stems/m^2. Arrange the greenhouse plants as twin growing rows with 0.6 m between growing rows and 0.9 m-wide walkways. Adjust plant spacing within the row to obtain the desired plant density. In rockwool culture, use 5 plants/180 cm slab — usually two, 90 cm slabs in a 2 m-long poly sleeve to form a single long slab. Space the long slab, as well as the stems, to obtain the desired plant density. Increasing the stem density from 6.0 stems/m^2 to 6.5–6.75 stems/m^2 by adjusting the spacing between the slabs is also an option. Train the stems to allow maximum light interception.

Growing Media

In Ontario, most of the pepper acreage is grown in rockwool or cocos-peat (coir) with a few acres in NFT. Soak rockwool slabs with the slab saturation solution at pH 5.2, and EC 2.0 mS/cm (Table 8–3, *Fertigation Schedule for Peppers (ppm nutrient)*, p. 66). After transplanting, use a nutrient solution with a suggested pH of 5.2 and an EC of 2.0–2.5 mS/cm. Adjust the EC based on rate of plant growth and available light. Too low an EC results in weaker plants susceptible to disease infestations. Too high an EC restricts growth, resulting in shorter internodes, thinner stemmed plants, and thin and smaller leaves. A limited canopy is of concern because fruit exposed to sunlight may be damaged due to sunscald [*Plates* 21, 22].

Moisture management of the transplant blocks is important to reduce the accumulation of salts at the base of the plant [*Plate* 23]. This damaged area may be the entry point for stem rot diseases such as Fusarium stem rot. During the production cycle, use a nutrient solution with a pH of 5.2–5.5, and an EC ranging from 2.0–3.0 mS/cm. Maintain a slab pH of 5.8 and EC of 2.5–3.5 mS/cm. This is achieved by adjusting the percent leach (*Rockwool Culture*, p. 33).

The volume and EC of the nutrient solution applied varies depending upon the available light, the size of the plant, as well as the greenhouse temperature and relative humidity. Apply a nutrient solution at 18°C–22°C. Begin irrigation 1–2 hr after sunrise and end 1–2 hr before sunset. Night watering may be required, especially when the heat demand is high on cold, windy nights and/or the relative humidity is low in the greenhouse.

Training and Pruning

Pepper plants, by nature, are multi-stemmed. Young plants branch after several weeks' growth, usually about the 6th–8th leaf stage. Subsequently, at every node a flower bud and a lateral branch or sideshoot develops. Remove these to create a 2-stemmed plant (about 2 weeks after transplanting). Remove the lateral branches or sideshoots by snapping or cutting off with a sharp knife. Conduct this process every 10–14 days. Flowers are not allowed to set until the 3rd or 4th node after the initial branching. Remove the flowers by adjusting temperatures (*Climate*, p. 65) or by hand. Do not allow the king flower to develop into a fruit in order to allow a larger plant to develop before fruit setting is encouraged.

Under certain situations, allow side shoots to develop. This choice depends on several factors. To increase leaf area the side shoot may be trimmed to allow one leaf to develop. In some cases, a flower at the first node of the side shoot can be left to develop into a fruit in an attempt to ensure fruit development at all levels (nodes), especially if the flower at the main stem node does not develop.

Pepper plants must be supported with twine tied at the base of the plant using a loose, non-slip knot and attached to the overhead wires 3.4–3.7 m above. Twist the twine around the plant in a loose spiral every 10–14 days. Operations without high wires can grow peppers by layering the plants similarly to tomatoes.

Climate

Peppers, by nature, are slow growing. They require a high temperature and fertility program to maintain a reasonable growth rate. Fruit quality and yield is determined by the ability to develop large, well-shaped flowers on strongly growing plants. Flowers formed on weak plants are usually smaller, poorly coloured and tend to drop off, or if they develop into fruit, result in smaller, poorly shaped fruit. Improper pollination resulting in poor seed set also produces misshapen fruit.

After transplanting onto the slabs, maintain air temperatures of 23°C day and 21°C night for 1 week to promote strong vegetative growth and rapid root establishment. This initial temperature regime discourages fruit set allowing for a better-balanced plant. (*Fruit Set*, at right) Approximately 7–10 days after transplanting gradually lower the night temperature to 18°C–20°C to encourage fruit set. A lower night temperature encourages strong flowers and good fruit set. To balance the fruit load:leaf area, manipulate the night temperature to adjust flower development and fruit set. To increase flowering (generative), use a lower night temperature whereas a high night temperature encourages a vegetative growth.

Pepper plants will flower at every node and sets fruit in flushes (i.e., about 4 fruits/stem). Flowers on the following 2–3 nodes will abort and then the plant will set fruit again. Manipulating the greenhouse environment to improve plant balance minimizes this gap. Removing flowers and/or poor quality fruit is also helpful in balancing the plant and ensuring a steady harvest.

A ventilation temperature 2°C–3°C above the heating set point is generally recommended, but may be adjusted to maintain optimum relative humidity (RH). A vapour pressure deficit (VPD) of 0.4–0.7 kPa is recommended. At the suggested growing temperature, this results in an RH of 70%–80%. In the early planting stages, the RH may be too low, making it necessary to use a temporary 2-mil clear poly as a humidity/thermal screen above the crop to raise the RH. Alternatively, fogging or misting the greenhouse also raises the RH. However, excessive RH increases disease problems.

Given how sensitive pepper plants are, it is important to have all the equipment necessary to maintain an optimum greenhouse environment. While a well-designed forced air heating system (i.e., one with heat delivery system in between the growing rows) may be used, it requires high management skills.

To maintain the desired greenhouse environment during the summer, screening or shading is necessary. A movable screen or shade curtain, activated when light and temperature levels are high, decreases stress to the pepper plants. Another option is to whitewash the greenhouse roof. Apply a low-level whitewash late April or early May, and a 2nd coat early to mid June. In late August remove the whitewash to maximize light penetration in the fall. Maintaining ideal conditions during periods of high temperature and light allows the plant to develop a good canopy — minimizing blossom end rot (BER) and sunscald (Table 8–2, *PEPPERS: Summary of Growing Recommendations*, p. 66).

Fruit Set

Fruit set in early-planted crops is delayed to the 3rd or 4th node on the main branches. Remove any flowers set below this level early in their development. This ensures the plant has sufficient leaf area to sustain the developing fruit load without causing a decrease in rate of growth and fruit development. Too early a fruit set results in small, poorly shaped fruit and increased susceptibility to blossom end rot (BER).

Harvesting and Storage

Harvest greenhouse peppers when they are fully coloured (>80% colour is present). Too early a fruit harvest delays full colour and shortens the shelf life. The highest financial return is obtained when harvested peppers are fully coloured.

Harvest peppers by cutting the fruit stalk with a small sharp knife. A clean, smooth cut decreases the incidence of disease pathogens and provides a pleasant appearance to the harvested fruit. Cut all fruit stalk stubs flush with the main stem. This encourages rapid healing and reduces diseases such as Fusarium stem and fruit rot, or Botrytis grey mould.

Fruit is graded to size and colour to ensure a uniform attractive product. If necessary, store peppers at 7°C–8°C. Ethylene released from fruit and vegetables stored with peppers may cause pepper fruit to over-ripen, decreasing shelf life and marketability.

TABLE 8–2. PEPPERS: Summary of Growing Recommendations

	Germination	Plant Raising	Transplanting	Harvest Stage	Full Harvest
Temperature**					
Day °C	25°C	21°C–23°C	24°C	21°C–24°C	21°C–23°C
Night °C	25°C	20°C–21°C	21°C	18°C–21°C	17°C–18°C
EC (mS/cm)	0.0–1.0	1.0–2.0	1.5–2.5	2.0–3.0	2.0–3.0
pH	5.2–5.8	5.2–5.8	5.2–5.8	5.2–5.8	5.2–5.8
Vol. of feed (L/day)*		0.2–0.3	0.2–0.3	0.5–1.5	1.5–2.0
Feed Schedule		A	B	C	D

* As required (watering strategies). ** Use lower settings when light level is low.

TABLE 8–3. Fertigation Schedule for Peppers (ppm nutrient)

	N	NH_4	P	K	Ca	Mg	Fe	Mn	Zn	B	Cu	Mo	S*	Cl*	HCO_3
A. Slab Saturation	200	10	50	253	247	75	0.8	0.55	0.33	0.5	0.05	0.05	100–150	50	25
B. For 4–6 wks after planting	180	10	50	370	190	75	0.8	0.55	0.33	0.5	0.05	0.05	100–150	50	25
C. Normal Feed	190	22	50	370	190	65	0.8	0.55	0.33	0.5	0.05	0.05	100–150	50	25
D. Heavy Fruit Load	210	22	50	370	190	75	0.8	0.55	0.33	0.5	0.05	0.05	100–150	50	25

* The fertilizers selected to create the nutrient solution will determine the final level of these anions.

	Kg/1,000 L Dilute 1:100			
Fertilizer	A	B	C	D
Calcium nitrate	112.11	82.11	82.11	82.11
Potassium nitrate	25.72	42.43	40.89	56.27
Monopotassium phosphate	6.75	6.75	6.75	6.75
Potassium sulphate	25.77	36.06	37.19	25.95
Magnesium sulphate	66.0	66.0	56.0	66.0
Ammonium nitrate	0.0	1.0	8.0	8.0
	g/1,000 L (Dilute 1:100)			
Iron chelate 13%	407.69	407.69	407.69	407.69
Manganese sulphate	165.78	165.78	165.78	165.78
Zinc sulphate	91.43	91.43	91.43	91.43
Borax	246.67	246.67	246.67	246.67
Copper sulphate	16.0	16.0	16.0	16.0
Sodium molybdate	10.87	10.87	10.87	10.87
Desired EC (mS/cm)	2.5–3.0	3.0–3.5	2.5–3.5	2.5–3.5
Desired pH	5.2–5.8	5.2–5.8	5.2–5.8	5.2–5.8
Vol of Water (L)	0.25–0.50	0.5–1.0	1.0–2.0	1.5–2.5

9. Lettuce Crop

Today, commercial greenhouse lettuce production is mainly grown hydroponically. Soil production was popular in the past, especially following a spring, soil-grown tomato crop. This kept staff busy and provided extra cash. However, changes towards monoculture and hydroponic tomato production ended this practice. At present, lettuce production is conducted exclusively as a single operation. Currently, the butterhead — known as Boston or Bibb lettuce — is the only type grown in the greenhouse. This type forms a loose head consisting of small tender leaves surrounded by the larger outer leaves rather than a tight head.

Greenhouse lettuce is primarily marketed to exclusive niche markets such as upscale restaurants, and fruit and vegetable markets, although increasingly more product is being shipped and sold by the supermarkets.

The average operation size is about 2,500 m^2, with the majority of production conducted in nutrient film technique (NFT) culture. In this system, plants are grown in a recirculated, continuously flowing film of nutrient solution.

Successful marketing of greenhouse lettuce requires a system designed to provide a continuous supply. This is accomplished with a 2-stage production system that has:

- a plant raising section where weekly seeding is conducted and transplants are raised
- a production section where transplants are grown to maturity and harvested.

To maximize efficiency, adjust plant spacing according to plant age/size. In the early stages of production plants are grown close together (4 in. × 4 in. or 100 cm^2 spacing) and then moved further apart once the leaves touch (8 in. × 8 in. or 400 cm^2) until harvest. To provide an average of 1,000 heads of lettuce per week, a growing area of 325 m^2 (3,500 sq. ft.) is required. This results in 8–10 production cycles per year (Figure 9-1, *Lettuce Yield Projection for Southwestern Ontario*).

Plant Raising

Sow seeds in flats containing a peat-perlite mixture by placing seed on the media surface and covering with a shallow layer of fine peat. Soak the flats with plain water at 18°C prior to sowing to prevent disturbing the seed distribution. Then cover the flats with a 2-mil clear poly to retain moisture in the media. A germination temperature of 15°C–18°C is optimal. Lettuce seed may not germinate if the temperature is too high. This is especially true in the summer. Decrease the temperature by shading the germination area or using misting systems.

After the first true leaves emerge (7–10 days), select the best seedlings and transplant in oasis or rockwool mini-blocks (3 ×3 ×3 cm). In some cases, seed can be sown directly into the oasis or rockwool mini-blocks or forestry seedling Jiffy 7s. For the Jiffy discs, place in a flat, soak with tap water and once fully swollen, place 2–4 lettuce seeds (usually leaf lettuce) in the opening at the top.

FIGURE 9–1. Lettuce Yield Projection for Southwestern Ontario

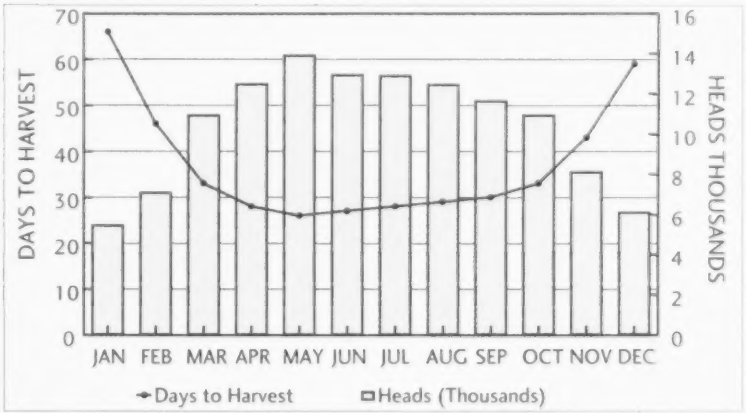


FIGURE 9–2. NFT Layout for Lettuce

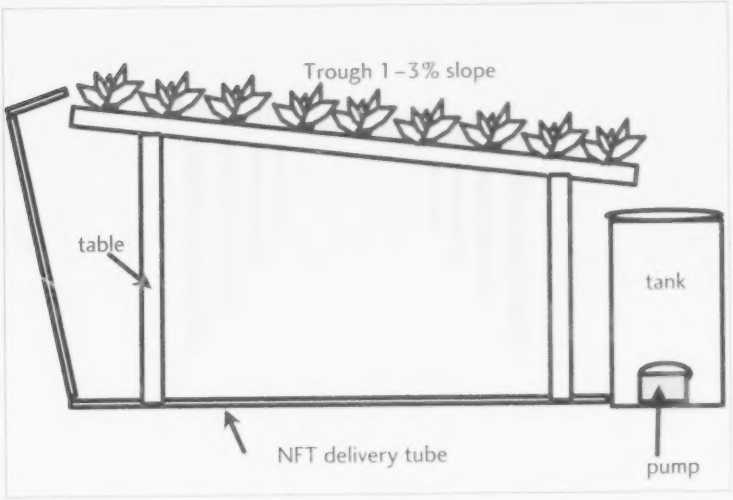
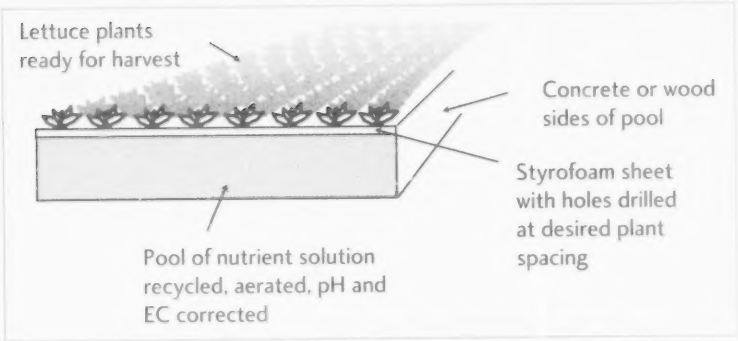


FIGURE 9–3. Float Raft Production System



Once seedlings reach the desired size, place the plugs in NFT troughs. Water the seedlings with a dilute complete nutrient solution (EC 1.0–1.5 mS/cm and pH 6.0) by overhead misting or sub-irrigation. Maintain a 15°C–18°C temperature and supplement with HPS (high pressure sodium) lighting at 20 watts/m^2 (24-hr photoperiod) and CO_2 at 1,000 ppm.

The 24-hr photoperiod, especially under low light levels in winter and cloudy days, enhances plant growth and decreases time to planting. Move young plants to permanent troughs after 3–4 leaves emerge (usually 3–4 weeks after sowing). Depending upon the seasonal solar radiation, growing temperature and CO_2 supplementation, harvesting can begin 4–8 weeks later. During summer, the time between sowing to harvest can be as short as 7–8 weeks, while in the winter it may be as long as 11–12 weeks.

Crop Production

There are numerous NFT trough systems designed for lettuce production. These may be as simple as a 10 cm (4 in.) PVC drainage pipe or an eaves trough, to an extruded trough with a channeled floor and built-in plant supports. In all cases, the trough provides a channel for the recirculating nutrient solution to flow and a support for the placement of the transplant (usually a cover through which the transplant is placed). The trough must be rigid enough to be moved (for adjusting plant spacing as the plants grow) as well as to be disinfected between crop cycles (Figure 9–2, *NFT Layout for Lettuce*).

Aeration of the root system is important — the system must be designed to provide a shallow film of fast flowing nutrient solution. If the film is too deep, a greater number of roots are submerged, resulting in poorly-aerated roots. These roots are weak, brown in colour, easily broken and prone to microbial infestation.

Aerate the nutrient solution in the mixing tanks by using a small pump that recirculates the solution back into the mixing tank via an overhead shower head type structure. An aerator — a device that increases the air in the solution as it is pumped back into the reservoir tank — can also be used. Design the return line and the reservoir tank so that the return water splashes into the reservoir tank, increasing aeration and mixing.

The mixing tank or reservoir needs a capacity of 1,000–1,500 L/1,000 m^2 (4,000–6,000 L/ac) to ensure adequate solution reserve and to provide a rapid response to EC and pH adjustment. Too large a reservoir tank may not respond rapidly to automatic additions of fertilizer and acid during production. Control EC and pH levels automatically to ensure optimal EC and pH ranges and to decrease EC fluctuations that promote tip burn. The EC level of the nutrient solution varies depending upon the time of year, stage of crop production, cultivar, and rate of growth. Table 9–1, *Fertigation Schedule for NFT Lettuce (ppm nutrient)*, p. 70, provides a fertilizer schedule for lettuce production.

An alternative production system for greenhouse lettuce is the floating culture (Figure 9–3, *Float Raft Production System*, p. 68). This method uses styrofoam sheets with holes drilled at specified plant densities that are floated in pools of nutrient solution. This system can be:

- 5 × 15 cm (2 × 6 in.) pressure treated lumber designed like a backyard hockey rink, lined with plastic
- elaborate concrete pools 30 cm deep
- ebb and flow tables altered to maintain a deeper water pool (3–5 cm).

The nutrient solution is recirculated, aerated, amended with fertilizers and acids to maintain the desired nutrient solution composition. The length and width of the pools vary to fit available space in the greenhouse or determined by the materials used. This system produces very successful crops.

Climate

Temperature regimes of the cropping cycle vary depending on seasonal solar radiation, the cultivar, the desired rate of growth and harvest date. In general, maintain night temperatures of 15°C–18°C with a light-dependent day temperature of 18°C–19°C (cloudy days) to 19°C–22°C (sunny days) and begin venting 1°C–2°C above the set temperature. Adjust the temperature regimes to maintain the weekly production goal. Manipulate the temperature gradually to prevent disease or lettuce tip burn incidences.

Lettuce can be grown as a cool crop (10°C night and 15°C–18°C day) especially during the winter when light levels are low. However, the days to harvest period is extended. Keep RH between 75%–85% or VPD 0.4–0.8 kPa. During the summer , when outside temperatures are high, do everything possible to keep a lower greenhouse temperature. Lettuce leaf/head quality is poor at higher plant temperatures.

Shade the greenhouses by using moveable shade curtains or applying whitewash to the outer greenhouse structure. Use fan and pad cooling systems or high pressure fogging systems. Avoid conditions that result in free water on the leaves or lower transpiration rate.

Supplement with HPS lighting (> 20 watts/m^2) during the winter and periods of cloudy weather to obtain an 18-hr photoperiod. Keep CO_2 levels of 1,000 ppm during periods of natural and artificial light.

Harvesting and Storage

Once lettuce has reached a marketable size (250 g), remove from the trough with the roots attached and place, roots first, in a poly bag. Tie off roots with an elastic band. Leave the bag open around the head of lettuce. Special clam shell clear plastic containers with a small trough for the roots are also available. Lettuce harvested without the roots is bagged bottom first and the top left open. Place the bagged lettuce in boxes containing 12–18 heads for shipping.

Lettuce quality deteriorates rapidly if improperly stored. Lettuce must be stored at 2°C–4°C at high RH (80%–90%). Freezing temperatures damage the product and too high a temperature results in further leaf development, reducing customer appeal. Store lettuce away from ethylene producing products (*Russet Spot*, p. 88).

TABLE 9-1. Fertigation Schedule for NFT Lettuce (ppm nutrient)

	N	NH_4	P	K	Ca	Mg	Fe	Mn	Zn	B	Cu	Mo	S	Cl	HCO_3
A	200	10	50	400	200	55	6	1	0.5	0.5	0.05	0.05	120	100	25

	Kg/1,000 L (Dilute 1:100)
Fertilizer	**A**
Calcium nitrate	87.37
Potassium nitrate	52.56
Monopotassium phosphate	6.75
Potassium sulphate	20.41
Potassium chloride	14.17
Magnesium sulphate	4.6
Ammonium nitrate	0.74
	g/1,000 L (Dilute 1:100)
Iron chelate 13%	4620.0
Manganese sulphate	380.77
Zinc sulphate	142.86
Borax	326.67
Copper sulphate	16.0
Sodium molybdate	10.87
Desired EC (mS/cm)	2.2–3.0
Desired pH	6.2–6.5
Vol of Water (L)	NA

10. Integrated Disease Management

Proper integration of disease prevention practices into the total crop management plan is critical to the integrated plant health within any greenhouse production system and the profitability of any business.

The basic objectives of any program should be to achieve at least the following:

- Reduce the possibility of introducing diseases into the crop.
- Avoid creating conditions conducive for disease establishment and spread.

A sound disease management program for any greenhouse crop integrates a few universal principles and concepts into the overall production system for that particular greenhouse crop.

It is important to understand the concepts of disease control, and the strategies developed from them, in order to make modifications appropriate for a particular greenhouse or crop situation. A disease control program involves more than a fungicide spray or drench schedule for the various crops grown. Too often, fungicide applications address the symptoms, not the problem.

The Disease-Triangle Concept

Three factors are necessary for disease development:

- A pathogen or disease-causing organism (e.g., a fungus, bacterium or virus).
- A susceptible plant for the pathogen to infect.
- A suitable environment in which the first two will interact.

For example, *Pythium* will attack seedlings when the rooting medium is cool (15°C–17°C) and wet, plant density is very high and sanitation generally poor.

The environment includes both the soil or media environment in which the roots grow and the above-ground environment where shoots, leaves, flowers and fruits are produced.

Growing media environment characteristics that must be considered include:

- pH
- nutrient levels and their balance
- EC
- moisture-holding capacity
- drainage
- oxygen content.

Aerial environment characteristics that must be considered include:

- light levels
- temperature
- air movement
- relative humidity
- air quality.

Six Principles for Plant Disease Control

Exclusion

- Preventing pathogens from becoming established in the greenhouse is a primary goal of disease control. For example, using sanitation measures such as footbaths, gloves, and coveralls by visitors assists in excluding disease pathogens from operations.
- Growers use soil-free media such as rockwool to minimize the incidence of soil-borne pathogens.

Avoidance

- This involves using practices to avoid situations that promote disease development. For example, plant wetness due to inadequate use of heating

and venting creates conditions favourable for the development of *Botrytis*.

Resistance

- This involves the inherent ability of a host plant to remain healthy or resist attack, even though a pathogen is present and/or the environment is conducive to pathogen development. For example, most new tomato cultivars are bred with genetic resistance to Fusarium crown and root rot and tobacco mosaic virus.

Protection/Prevention

- Fungicides can be applied before any disease is observed. These often protect crops during periods when conditions are conducive to disease development. For example, milk reduces the incidence of virus infections such as pepper mild mottle virus in peppers.

Eradication

- Steam pasteurization of growing media can eliminate root-borne diseases and nematodes. Sanitizing products can effectively control bacteria or fungal spores in dust or on surfaces of benches, in/on irrigation lines and emitters, and on tools used for propagation or production.

Therapy

- Treat infected plants to slow further sporulation and spread of the fungus. For example, Nova sprayed on cucumbers suppresses powdery mildew.

Basic Integrated Disease Control Strategies

Environmental Manipulation

Environmental manipulation includes air temperature, RH, light levels, air circulation, as well as media composition, pH, EC and water content.

- Know and understand the conditions required for the optimum growth of the crop and for the common diseases of that crop.
- Avoid extremes or, more importantly, rapid changes in relative humidity. This minimizes the time period and conditions suitable for *Botrytis* or powdery/downy mildew to develop.
- Be aware that temperatures of leaf surfaces can be lower than air temperatures due to radiation heat losses.
- Avoid poor air circulation within the greenhouse. This can cause uneven temperatures throughout the crop. It can also lead to free moisture forming on the plants, particularly at night, creating ideal conditions for mildew and *Didymella* infections.
- Avoid *all* extremes, as much as possible, for the crops. For example, over-fertilization promotes *Fusarium solani* in peppers, while the combination of very high or low temperatures and overwatering favour development of *Pythium*.

Modification of Cultural Practices

Chronically stressing plants makes them more susceptible to attack by disease pathogens. Plants are stressed when the root and/or shoot environments are neglected.

- Understand the growing requirements of the crops being produced. Not all crops will tolerate the same conditions.
- Monitor the media or substrate pH and EC every week.
- Avoid high salt levels (high ECs) in the growing media when soluble salts are high. High salts damage root hairs and young roots. These wound sites become entry points for disease pathogens.
- Use clean containers and porous, well-draining media to minimize the potential for pathogens such as *Pythium* and *Fusarium*.
- If foliar diseases are an ongoing problem, review temperature, relative humidity, air circulation patterns and watering practices. Often, by maintaining higher night temperatures or higher minimum pipe temperatures, and proper venting, the incidence of foliar diseases can be lessened.

Sanitation and Roguing

Sanitation is the first step in any disease management program. If a source of infection or infestation is constantly present due to poor hygiene, disease management programs will be expensive and frustrating. Carry out good sanitation practices as the first line of defence in the greenhouse and adjoining structures (boiler rooms, etc.) in the immediate vicinity of the greenhouse and during every stage of crop production.

Proper greenhouse sanitation is a continual, year-round process. **Cleanliness on its own may not totally control pest problems, but it is a basic component of any control program**. It is important to:

- Use footbaths between different greenhouse compartments. Routine maintenance of these footbaths is essential. Follow the label of the product being used.
- Remove dead and dying plants. Place in bags when removing from the growing row.
- Place rogued plants in commercial garbage containers and dispose of them in a landfill to reduce potential sources of inoculum.
- Dedicate wheelbarrows or carts used to discard diseased material strictly for disposal purposes. If this is not possible, disinfect after every use.
- Have employees wear disposable gloves when handling diseased plant material. Otherwise, employees should wash their hands thoroughly with soap or bactericidal hand lotion before performing another function. Note that hand washing is not as effective as using disposable gloves.
- Keep normal crop residues well away and downwind from the greenhouse to prevent particles of media or plant tissue from being blown or sucked into the greenhouse. Preferably cover plant residues or, alternatively, move residues off-site on a routine basis to a land fill or composting site.
- Keep walks and the surfaces of benches clean.
- Carefully check both the foliage and roots of transplants for disease. Isolate any suspect seedlings.
- Maintain good drainage to eliminate puddles and wet surfaces, as these provide ideal breeding sites for fungus gnats and shoreflies. These insect pests are a possible source of infection for root diseases such as *Pythium* and *Fusarium*.
- Keep the greenhouse and immediate surroundings free of weeds and ornamentals that may harbour diseases like pepino mosaic virus (PepMV), beet pseudo yellows virus (BPYV) and cucumber mosaic virus (CMV), or insects that can be vectors of disease.
- For soil-grown crops steam soil before planting winter crops to minimize the carryover of root and crown rot pathogens.
- Dip cutting knives in disinfectant between plants or at least at the ends of rows to prevent the spread of disease.
- Between crops, perform a general disinfection of the greenhouse structure, heating pipes, walks, benches and all harvesting equipment.

Disinfectants

Disinfection, or the removal of disease-causing organisms from surfaces of the greenhouse and the accompanying equipment and tools, is a crucial step in the general cleanup at the end of the season. This step is critical to minimizing carryover of disease-causing organisms to subsequent crops. To disinfect properly, it is important to understand the disinfection process and the range of activity of the disinfectants.

Factors affecting effectiveness of disinfectants

- Remove all inorganic (e.g. fertilizer deposits) and organic (e.g. plant debris) matter from surfaces. Scrub textured surfaces with a detergent or commercial grade cleaner and a power washer.
- Pay special attention to horizontal surfaces, such as rafters, tops of overhead piping, etc. Such areas must be cleaned by power-washing from overhead on a lift.
- Remove all organic matter and deposits (including calcium deposits) from all surfaces and objects to be disinfected, including lines, drip stakes etc. Any organic matter or residues present will react with the disinfectant and reduce its effectiveness. If acid is used to remove calcium deposits, rinse the lines before using disinfectants to avoid chemical reactions and production of dangerous gases.
- Do not use hard water, i.e. water with calcium ions in excess of 300–400 ppm, because it destroys the disinfecting ability of certain chemicals.

- Ideally, mix disinfectants in warm water (approx. 20°C) and apply the solution to dry surfaces during the evening in a warm greenhouse. In general, lower temperatures require longer contact times between the disinfectant and surfaces, whereas higher temperatures increase efficiency by two- to three-fold for every 10°C rise in temperature.
- Always use the proper concentration because inadequate concentrations may result in lack of disinfection and excessive concentrations may adversely affect materials that contact the disinfectant.

Effective Disinfectants

Two commercial disinfectants registered for use in greenhouses in Canada are Chemprocide® and Virkon®. As with any chemicals, always carefully read labels for all disinfectants before use, follow all safety precautions, particularly in terms of protective wear, and consult distributors of the products for advice on most efficient use of these products.

Pathogen-Free Plant Material

Do not bring in new plants until the old crop has been moved out and the area thoroughly sanitized. Alternatively, isolate the new plants in a separate area. This is not possible when interplanting a crop, but take care to minimize contact between the new and old crop.

Vector Control

Many viruses are spread by insects. For example, aphids spread cucumber mosaic virus in cucumbers and thrips can spread TSWV/INSV in tomatoes and peppers.

Consider screening vents to reduce the number of insect pests that enter the greenhouse. This can make biocontrol programs easier by generally suppressing pest population levels and by excluding larger pests such as cabbage loopers and lygus bugs. (OMAF Factsheet, *Screening of Greenhouses for Insect Exclusion*, Order No. 00-021)

- Fungus gnats are now known to spread the spores of *Pythium*. The larvae damage young roots through feeding activity. Research has shown that *Pythium* oospores (thick-walled sexual spores) are routinely transmitted through the gut of fungus gnat larvae. As well, the adult can transfer the pathogen with its legs and mouthparts.
- Controlling algae growth and providing adequate drainage helps control insect populations and minimize the spread of disease pathogens.

Host Plant Resistance

Some cultivars of crops are less susceptible or have more tolerance to certain diseases than others.

Chemical Control

Fungicides have been the conventional approach to disease control. The role of fungicides can vary from protecting healthy plants to treating infected plants and eradicating diseases. Rotation of fungicides with different modes of action is necessary to reduce the likelihood of resistance developing.

Biological Control

Biological control of diseases involves the use of fungi and bacteria that strongly suppress disease-causing organisms without harming the crop. Mechanisms of action include competition, antibiosis, parasitism or induced resistance. Most biocontrol products should be considered preventative and their use started with the planting of a crop.

Two microbial fungicides, Mycostop™, and Rootshield™, are registered in Canada for use on greenhouse crops for suppression of root diseases. Mycostop is registered for the control of damping off, root and stem rot, and wilt caused by *Fusarium*, *Pythium* and *Phytophthora*. The soil bacterium, *Streptomyces griseovirdis*, is the active ingredient and uses hyperparasitism and antibiotic production as its modes of action. Because the effect is preventive, Mycostop is best used as early as possible in the crop's life and repeated as per label instructions.

Rootshield provides protection by colonizing the surface of the roots and root rhizophere through the utilization of waste products produced during normal root growth. It also parasitizes disease-causing fungi through the release of enzymes that cause breakdown of their cell walls. Apply the product soon after germination and/or transplanting. Two formulations are available: a granular formulation that can be incorporated into the growing media or a drench to be applied to newly transplanted seedlings.

Generally, microbial biocontrols are primarily suppressive and must be integrated with other management strategies for optimum results.

Success Criteria

- Emphasize prevention rather than cure.
- Monitor crops weekly.
- Walking the crop(s) is essential to early detection. This means checking the crop foliage and root systems and environment conditions.
- As a grower/manager, keep detailed records that enable merging of cultural, environmental and insect and disease data for analysis, e.g. crop registration and path registration programs
- Include weather data to help anticipate potential disease problems. For example, a cool, cloudy and wet summer without proper climate management (heating and venting to manage RH) creates ideal conditions for many diseases such as downy mildew, late blight, gummy stem blight, *Botrytis*, etc.
- Correct diagnosis is crucial. Without correctly identifying the pathogen, control using cultural or chemical strategies is impossible. Soil-borne fungi are the most difficult pathogen for growers to identify. Send samples to the Pest Diagnostic Clinic, University of Guelph, for accurate diagnosis. See Appendix A, *OMAF Staff*, p. 133 for further details. For some diseases, ELISA disease diagnostic kits for grower use are available from some local distributors.
- Develop a thorough understanding of the diseases that affect the crops being grown. Correct use and timing of management strategies then becomes part of an ongoing process.
- Because disease pathogens are microscopic, learn to anticipate when possible pathogen infection periods are likely to occur. By the time the problem is visible, the pathogen has usually been present for some time and is more difficult to control.

11. Diseases

Diseases in greenhouse crops are caused by fungi, bacteria and viruses. Control of many of these diseases can be managed by:

- sanitation and hygiene
- cultural practices such as nutrition and pruning
- greenhouse environmental management.

Plate 24 is an example of a situation that easily leads to disease outbreaks.

Tomatoes

Tomato Diseases Caused by Fungi

Corky Root Rot (*Pyrenochaeta lycopersici*)

Infected plants show a lack of vigour (thin heads) and wilting or flagging on sunny days. As the disease progresses, foliar chlorosis (yellow-brown chlorosis on the lower leaves) and more severe wilting is visible. Early signs of disease are light brown lesions on the root surface. These are closer to the base of the plant in older roots. On larger and older roots, dry brown, swollen corky lesions are visible. The corky layer easily peels off revealing the vascular root tissue (stele). This is commonly known as 'rat-tail'.

Corky root is a slow disease and death of the plant takes a long time. That is why crop management is so important. Encouraging aggressive root systems — where new roots are continuously developing — minimizes problems associated with the disease. Do not plant in cold media. In rockwool culture, the infected plant eventually infects the companion plant in the bag. At the end of the season, discard this bag, as steam sterilization may not be able to penetrate the large infected roots where the pathogen is located.

Damping-Off and Late Damping-Off (*Pythium* and *Rhizoctonia*)

Given the wide use of hydroponic culture, with its inorganic growing media, early damping-off is not a common problem today. Seeds, in general, are treated.

Early damping-off decays the seed or seedling prior to emergence. With late damping-off, the base of the seedling narrows and collapses, causing seedlings to topple [*Plate* 25].

Minimize the problem by:

- ensuring sanitary conditions during seed sowing
- maintaining ideal media temperatures
- watering with warm water (18°C–22°C)
- using sterile growing media
- using clean water (avoid soil-contaminated water from wells or creeks)
- disinfecting water if not clean
- using well-drained media.

Water the seedlings in the morning so the leaves and stems are dry before nightfall. Keep a clean starter house and sowing bench.

Fusarium Wilt and Verticillium Wilt (*Fusarium* sp. and *Verticillium* sp.)

Initial symptoms are a yellowing of the lower leaves and wilting. The yellowing begins in the older leaves, resulting in epinasty, where the leaves and growing tips bend downwards. Generally, a bright yellow discoloration of the interveinal tissue with brown to orange marks can be seen. There is a brown discoloration in the vascular tissue that extends high up the plant. Leaf petioles may also exhibit vascular discoloration in severely affected plants.

Most greenhouse cultivars today are resistant. However, there have been several reports of Verticillium wilt incidence on resistant cultivars in greenhouse tomatoes in Ontario. Greenhouse sanitation is the best remedy.

Fusarium Crown and Root Rot (*Fusarium oxysporum* f. sp. *radicis-lycopersici* (FORL))

Plants infected with this disease wilt on sunny days, have a thin head, flaccid leaves and weak flowers. First symptoms are usually seen when plants are fully loaded, at the 6–8 cluster development stage. A chocolate brown discoloration at the base of the plant and ground level is usually visible and the roots are brown. Examination of the vascular tissue (splitting open of the stem base) displays a chocolate brown discoloration that extends 5–25 cm above ground level [*Plate* 26].

Most modern tomato cultivars have resistance to FORL. However, some desirable cultivars do not; consider grafting onto a resistant rootstock.

Grey Mould (Ghost Spot) (*Botrytis cinerea*)

This common disease affects all aerial components of the plant and is prevalent in greenhouses where the environment and crop management is not optimal. Symptoms may be seen on the stem, leaf, fruit and harvested fruit truss, as well as any wounds or pruning cuts that have not healed properly.

In most cases, the classical brown lesion, often with concentric banding and grey fungal growth, is readily seen [*Plate* 27]. Early symptoms on the stem are elliptical water soaked lesions from which the mouldy-grey growth develops. Typical early leaf symptoms begin at a point of injury. This can be a result of:

- damage by workers
- guttation — exudation of moisture from the leaf edges or tips usually when RH is high/VPD is low and root pressure is high
- poor greenhouse environment.

As the disease progresses it develops a grey mould that covers the whole leaf. Ghost spot is the term used to describe symptoms on the fruit. This is a light coloured circular mark with a whitish-brown pinpoint in the middle [*Plate* 28].

Improving greenhouse environment and cultural practices decreases the incidence of *Botrytis cinerea*. *Botrytis cinerea* may infect the plant early in its life cycle (starter house or shortly after transplanting), but may not manifest itself until the plant is undergoing stress. This usually occurs prior to picking, 6–8 weeks after infection has occurred. Management includes:

- adjusting the greenhouse environment
- increasing heating and venting to prevent free water on the plants
- lowering the RH or raising the VPD
- raising the EC
- deleafing early in the day, allowing wounds to dry before nightfall.

Infected stem tissue may be cut out to decrease potential spores and prevent girdling (results from complete invasion of the stem tissue and causes death).

Leaf Mould (Fulvia fulva) (Syn. *Cladosporium fulvum*)

The first symptoms are yellowish-green indefinite areas on the upper surfaces of lower leaves. This is accompanied by purplish, velvety fungus growth on the underside. These symptoms are very similar to severe magnesium deficiency and may be confused with it. However, with magnesium deficiency there is no fungal growth on the leaf underside. Leaf mould spreads rapidly under humid conditions and quickly moves towards the top of the plants.

Modern greenhouse tomato cultivars are resistant to this pathogen. However, maintain ideal greenhouse environment conditions to prevent unnecessary infections.

Powdery Mildew (*Oidium neolycopersici*)

This is a recent disease now quite common in Ontario tomato greenhouses. Incidences have occurred as early as the seedling stage. Early symptoms are yellow spots or blotches on upper leaf surfaces, with white powdery growth on the undersurface. In severe infestations, these lesions coalesce to create a white powdery fungal growth on the leaf surface and stem [*Plates* 29, 30].

This disease spreads very rapidly under conditions optimal for maximum tomato production. At first sign of this disease, treat the whole operation to minimize long-term problems.

Tomato Diseases Caused by Bacteria

Bacterial Canker (*Clavibacter michiganensis* ssp. *michiganensis*)

This is a very contagious and destructive disease of greenhouse tomato crops. The first symptom is usually a wilting of the upper leaves, one-sided wilting, with areas of dead or dying tissue on lower leaves [*Plate* 31]. In later stages the fruit may take on a

whitish, mottled colour, instead of the normal green colour of the developing fruit on a normal plant [*Plate* 32]. Diseased fruit often drop off prematurely, especially if the plant is given a sharp shake. Inconspicuous, yellowish coloured pustules or lesions may occur on the surface of the stems and leaves. These contain large numbers of bacteria that are easily carried by workers from diseased to healthy plants. It is important to recognize canker at an early stage and to remove infected plants before a major epidemic occurs.

Isolation is the best management technique to curb the spread of this disease.

- Place infected plants and three neighbouring plants on either side in garbage bags and discard (incinerate or bury).
- Staff who remove the infected plants must shower and change into clean clothes before re-entering the greenhouse.
- Isolate the row from which the diseased plants were removed.
- Do not allow all personnel to enter the row(s) with infected plants.
- Assign one person to perform all work in this row. This person must wear coveralls to be used exclusively while working the infected row.
- Limit work in the diseased rows to the end of the day to minimize risk of disease transfer.
- Assign equipment, such as picking carts and boxes/crates, specifically for the infected row, or disinfect before moving into other areas of the greenhouse.

Sanitize the greenhouse and all equipment properly at the end of the crop to minimize disease recurrence.

Bacterial Stem Rot (*Erwinia* and *Pseudomonas* spp.)

The first symptom is the sudden wilting of a few plants, scattered throughout the greenhouse. These plants will have hollow stems about 20–40 cm above the ground, have a foul odour and may be filled with decaying plant tissue. In some cases, a dark chocolate brown discoloration may be seen at the nodes. Infected plants tend to be soft vigorous plants and primarily in gutter rows with condensate dripping. Infection usually occurs through a wound where a sucker, leaf or cluster has been removed [*Plate* 33].

To curb this disease, alter the greenhouse environment by:

- increasing the VPD or lowering RH
- allowing no condensation of water on the plants
- changing the plant vigour with a higher EC, lower water application, and/or reducing nitrogen levels
- keeping plants dry.

This disease is seen in poorly managed crop and greenhouse environments and has not been a major problem in Ontario greenhouses.

Bacterial Wilt (*Ralstonia solancearum*)

Symptoms of this disease include wilting, browning of the vascular tissues in the lower parts of the stem, yellowing and streaking of the stem, and development of adventitious roots at the base of stems. Note however that *Ralstonia solancearum* can be latent in healthy tissue (i.e. be present but not show symptoms until a later date) and this makes early detection based on symptoms difficult.

Infection normally takes place through the roots and is easily spread via re-circulating systems where the infested recirculating water is not disinfected. It can spread on infected plant material, however, local spread within the greenhouse is through water splashing or the movement of water through the growing media. Plant to plant spread may also occur if the root system of healthy plants comes in contact with those of infected plants. It can also be spread via infected tools and on contaminated clothing or hands. It is not airborne but can survive in waterways.

Ralstonia solancearum is a serious bacterial soilborne pathogen that causes wilting and death in solanaceous crops such as tomatoes, potato, tobacco and eggplant. Peppers grown in the field are not as susceptible as these other crops, but they can be, under tropical and subtropical conditions.

Managing this disease consists primarily of quarantine and sanitation measures. It is a systemic disease and very difficult to control otherwise. Test any suspect plants at an approved diagnostic clinic.

Bacterial wilt or southern bacterial wilt caused by *Ralstonia solancearum* is not present in Canada at this time, however, it has occasionally been introduced into floriculture greenhouses and field tomatoes on contaminated seedlings from Southern and tropical countries. There are 5 races (Races 1 to 5) and

5 biovars of *R. solancearum*. The term "race" is based on host range, while "biovar" is based on its biochemical reactions. *Ralstonia solancearum* Race 3 Biovar 2 is a regulated, quarantineable pathogen in Canada, Europe and the U.S. It is has also been placed on the USDA's Agricultural Bioterrorism Act of 2002 Select Agents and Toxins list.

Due to the survival ability of this pathogen under temperate conditions and its threat to the tomato and potato industries, any plants diagnosed with Race 3 of *Ralstonia solancearum* have to be disposed of by the Canadian Food Inspection Agency (CFIA).

Race 3 is of special concern to the potato industry in the U.S. and Canada because it is has been shown to survive in soil in temperate climatic regions and has caused severe losses in potato crops in other temperate countries. Race 3 is most severe between 24°C–35°C (optimal temperature is 27°C) and decreases in virulence when temperatures exceed 35°C or fall below 10°C. Race 1 is endemic in the U.S. particularly in the southern parts where it causes severe disease damage on field grown tomatoes. All the other Races are usually found in tropical and subtropical regions of the world.

Tomato Diseases Caused by Viruses

Cucumber Mosaic Virus (Shoestring)

This virus produces narrow, spindly, mottled leaves on the upper portions of tomato plants. Infection is common when aphids and other insects move into the greenhouse, carrying the virus from outdoor cucumber or melon crops, beans, alfalfa or from a number of weed species known as symptomless carriers. Infected plants may not die, but they rarely produce a marketable crop.

Remove infected plants to minimize further spread of the infection and control pests. Keeping areas within and around the greenhouse weed free will reduce the source of the virus.

Pepino Mosaic Virus

Symptoms of this virus disease are generally more readily seen under low light and temperature conditions. During warmer, brighter months, older plants may harbour the virus but not show any symptoms. Symptoms usually appear 2–3 weeks after infection and tend to spread along the row [*Plates* 34, 35, 36]. Plants infected with this disease may display fern-like leaf growth, a yellow and green mosaic, interveinal yellowing of leaves resembling magnesium deficiency, necrotic spots, browning of the stem and calyx, and uneven fruit ripening. Crops affected by Pepino mosaic virus (PepMV) include tomato, potato, eggplant, tobacco and their relatives. Pepper is not yet known to be a host.

Pepino mosaic is **very contagious and easily spread** mechanically via plant sap on shoes, clothing, direct plant-to-plant contact and propagation (grafting, cuttings). Pepino mosaic virus can be spread over long distances via the sap in infected fruits and survives for about 4 days on clothing and shoes. In organic debris that is moist and held at 10°C, the virus remains stable and capable of infection for 4–5 weeks.

Management strategies for this disease are based on biosecurity strategies and include:

- limited access by visitors, particularly from other greenhouse operations
- practising general sanitation measures such as use of footbaths, gloves and coveralls
- disinfection of footware before and after entering greenhouse operations
- marking off affected areas of the greenhouse to ensure that workers do not move from infected to non-infected rows
- changing clothes and thorough washing of hands after working in a contaminated area and before moving into a non-infected area
- disinfection of all crates, carts, and tools
- dipping gloved hands in skimmed milk or disinfectant between plants
- using vegetative varieties or cultural measures such as grafting that promote plant vigour
- keeping inside and the immediate surroundings of the greenhouse free of weeds and ornamentals since some of these may be hosts of this virus
- disposing of infected crop residues by burying, burning or composting. Do not dispose of crop residues in fields surrounding greenhouses as this could serve as a source of reinfection for susceptible crops and weeds, and ultimately, the greenhouse crop itself.

See also management procedures for *Bacterial Canker*, p. 78.

Tomato/Tobacco Mosaic Virus

Tomato (ToMV) and tobacco mosaic virus (TMV) were ongoing problems in Ontario greenhouses until the use of resistant cultivars. Although both viruses can infect tomato, ToMV tends to be restricted to tomatoes and TMV to tobacco. Other plant species that can be infected by these two viruses include pepper, tobacco, petunia, snapdragon and many weeds. Symptoms caused by ToMV and TMV are very similar. The type of symptoms produced depends on the virus strain (at least 5 strains of ToMV exist), cultivar, plant age, temperature and light conditions. Symptoms could include wilting, mottling or green yellow mosaic of leaves, fern-like leaves, stunted growth, blotchy, distorted fruits, internal browning of the fruit wall and abortion of flowers and developing fruits.

Sources of these viruses include seeds, infected tobacco products, plant debris, soil and weeds. Plants can also be infected via damaged roots exposed to contaminated nutrient solutions. These viruses spread very rapidly by the rubbing of infected plants against healthy ones, and by contaminated hands, tools and clothing. These viruses are not normally spread by insects. Tomato mosaic virus and TMV are very stable and can survive for a few years in plant residue in the soil, and on stored, unwashed clothing.

Using resistant cultivars is the best approach for managing this disease. If using susceptible cultivars, do not allow workers to smoke in the greenhouse. Ensure that smokers wash and disinfect their hands before re-entering the greenhouse. In the event of an infection, carry out management practices as outlined for *Pepino mosaic virus*, p. 80. In addition, use undiluted skim milk, powdered skim milk (100 g/L) or a disinfectant for dipping tools and gloved hands while working in the crop.

Tomato Spotted Wilt Virus/ Impatiens Necrotic Spot Virus

Both tomato spotted wilt virus (TSWV) and impatiens necrotic spot virus (INSV) are very similar in biology and are both spread by western flower thrips. These viruses have a wide host range and are generally similar. However, the recorded hosts of INSV appear to be less and it is more frequently found on ornamental crops than on vegetables. Susceptible hosts include tomato, pepper, eggplant, lettuce, cucumber, cauliflower, tobacco, chrysanthemum, petunia and many weeds. These viruses also differ in that eight additional thrips species can vector TSWV, but not INSV.

Symptoms vary and include bronzing, dark brown spots on young leaves, dark brown streaks on stems and leaf petioles, stunted growth, mottled fruit with light green rings with raised centres, and alternate orange or yellow and red bands in ripe fruits [*Plate* 37].

Thrips provide the most important means of transmission, but TSWV can also be seed-transmitted.

This virus is acquired only by the larval stage and transmission is due almost exclusively to the adult thrips. Adults infect plants during feeding and remain infective for the rest of their lives (22–30 days). Adults do not transmit the virus to their young.

Management of this disease includes:

- roguing and proper disposal of infected plants
- keeping the interior and external surroundings of the greenhouse free of weeds and ornamentals
- monitoring for thrips using yellow or blue sticky cards
- inspection of plants for feeding damage symptoms
- management of thrips populations
- screening of vents, etc. to reduce movement of thrips into the greenhouse.

Tomato Physiological Disorders

Blossom End Rot (BER)

This physiological disorder is commonly seen as a firm, dry, sunken and discoloured area (brown or black) at or near the blossom end. It may be very small (less than 0.5 cm in diameter) to large, where over half the fruit is affected [*Plate* 38]. It is caused by the lack of calcium movement to the distal end of the fruit, resulting in poor cell integrity and cell breakdown. The lack of calcium may be due to:

- lack of calcium supply
- high EC (prevents or decreases water uptake)
- low moisture in the growing media and erratic watering strategy
- excessive vegetative growth (majority of calcium moved to the leaves)

- dramatic change in fruit growth resulting in higher calcium demand than the supply to the afflicted tissue
- high VPD (or low RH) resulting in excessive transpiration and decreasing water movement (and calcium movement) to the fruit
- poor root system due to lack of aeration thus decreasing water and calcium uptake.

Blotchy Ripening

This disorder causes a type of uneven ripening, where certain areas on the tomato surface remain green or yellowish-green while other areas develop to their normal colour. Some known causes of blotchy ripening are low fertility levels, inadequate potassium, overcrowding, excessive fruit surface temperature, mosaic and other viruses [*Plate* 39].

Blocky or Pointy Fruit

The symptoms are the plants' response to vegetative action under low light conditions, particularly during winter and early spring. Some cultivars are more susceptible than others and a strong vegetative impulse such as low light, excess water and low EC will cause the fruit to become blocky and/or pointy. In the summer, pointy fruit is usually a response to high temperature stress [*Plate* 40].

Catface

This condition occurs during periods when greenhouse temperatures are not maintained at a level adequate for normal fruit setting. Such fruits become misshapen and have irregular protuberances at the blossom end. Streaks and bands of dark greenish, scaly scar tissue often occur at the blossom end or at the sides of the tomato fruit.

Puffiness

Puffiness or hollow fruit may occur due to inadequate pollination or incomplete nutrition and/or conditions of low light. Frequently only one or two tomatoes on an individual truss may be affected. Fruits on subsequent clusters may not be affected if environmental conditions improve.

2,4-D Injury

This herbicide was used for many years for weed control in field crops and lawns. Occasionally, greenhouse tomato crops are damaged by 2,4-D drift or from contaminated sprayers. Plant symptoms are often similar to those caused by shoestrong and/or other viruses, where leaf growth becomes spindly, distorted and corkscrew-like, blossom set is reduced and fruit that do set are misshapen.

Nutrient Deficiencies and Toxicities

An imbalance of nutrients within tomato plants may cause various leaf symptoms that resemble disease. Most common is magnesium deficiency, which causes an interveinal light green discoloration of the older leaves, especially during periods of heavy fruit load [*Plate* 41]. Fortunately, greenhouse tomatoes are able to withstand a certain amount of magnesium deficiency without significant yield loss.

Low levels of calcium result in BER as discussed earlier on p. 81. Potassium deficiency causes the edges of the young upper leaves to display a leaf edge chlorosis as well as blotchy ripening [*Plate* 42]. Iron deficiency may also occur where leaves at the tops of the plants turn a mottled light green to lemon yellow [*Plates* 43, 44]. If severe, this causes a thinning of the upper stems and reduction of fruit set on the upper blossom clusters. A deficiency of manganese produces symptoms similar to iron deficiency. The most common symptom of manganese toxicity is a darkening of the main veins of the younger leaves, plus a browning and destruction of adjacent leaf tissue. Yellow discoloration of the distal leaf with darkening of the midrib is a result of boron deficiency [*Plate* 45].

Russetting

This disorder is present in some tomato cultivars and can be a problem as fruit quality is adversely affected. Russetting, or shrink cracks, are minute hair-like cracks on the shoulders of tomato fruit. In mild cases, these cracks are visible under indirect light, but in severe cases, are readily visible. Russetting can be seen on immature green fruit as well as on mature ripe fruit [*Plate* 46]. In severe cases, the shoulder remains a grey-green colour, while the remainder of the tomato ripens normally [*Plate* 47].

It is thought that the fruit expands at a rate faster than the ability of the skin to expand, causing these minute cracks to occur. Try to select a cultivar less prone to russetting but able to retain fruit size, plant habit, etc.

Techniques that help minimize russetting are: proper water management, plant balance, fertilizer schedule and greenhouse environment.

Cucumbers

Cucumber Diseases Caused by Fungi

Black Root Rot (*Phomopsis sclerotioides*)

This disease is quite common in cucumber crops grown in unsterilized or unpasteurized soils. While disease incidence has decreased with the increase of rockwool culture, it may occur where greenhouse hygiene is poor. This is especially true during the plant raising stage, as contamination with infected soil may occur more readily.

Infected plants exhibit wilted leaves that recover at night. As the disease progresses, the recovery decreases, resulting in weaker heads, poor fruit set, permanent wilting and eventual death. This usually occurs in conjunction with other pathogens. Examination of the roots with a hand lens reveals black rectangular discoloration patterns like a checkerboard along the infected root.

Pasteurizing the growing media and proper hygiene are key methods of decreasing infection.

Damping-Off and Late Damping-Off (*Pythium* and *Rhizoctonia*)

Early damping-off and late damping-off symptoms are similar to those in tomatoes (p. 77). The same organisms attack the cucumber roots of mature plants in rockwool culture — especially if conditions in the root zone are not properly managed. This results in wilting of the upper leaves during the day (more severe on sunny days) with recovery at night. However, this eventually leads to death. Affected plants also display brown-orange lesions at the base of the plant that may extend 10 cm along the stem. Roots are severely affected and are brown and easily broken off.

Proper water management is the best strategy to minimize Pythium problems in mature cucumber plants. Overwatering and poor aeration are the two main causes of *Pythium* in cucumber crops. Adverse root zone temperatures (too low or too high) also promote *Pythium* infestations. Avoid water that may be contaminated by soil (well or creek). Disinfect this water before use.

Grey Mould (*Botrytis cinerea*)

Botrytis cinerea attacks leaves, fruit and upper stems of cucumber plants. It is a result of poor crop management and environmental control. Classical grey mould symptoms (brown lesions with grey fungal growth) are visible at wound sites (nodes, fruit stems, broken leaves) and in severe cases, on the flower and tip of fruit [*Plate* 48].

Heat and ventilation, as well as proper pruning of stems and fruit stalks (clean cut without ragged edges), is the best approach to minimizing the incidence of *Botrytis cinerea*.

Gummy Stem Blight (*Didymella bryoniae*)

This is a common greenhouse cucumber disease, prevalent in most greenhouses. It is readily managed through proper cultural practices and environmental conditions. The disease attacks the stems, leaves, flowers and fruits. Symptoms are similar to those of *Botrytis*. However, a key difference is that on the stem, black pinpoint lesion spots (fruiting bodies of the fungus) are seen when viewed with a hand lens. Lesions on the stem may also exude a tan-coloured gummy exudate. The leaves show V-shaped yellowish-brown lesions. Usually, the fruit do not show any visible external injury; however, infected fruit tend to have a pointy blossom end. A brownish-yellow discoloration of the centre tissue is seen on the infected fruit when the blossom end is cut along its length [*Plates* 49, 50].

The pathogen may survive up to two years in a dormant stage in undecomposed plant debris that is a source of inoculum. The gummy stem blight pathogen requires a wound site to enter the plant and cause damage. Under ideal conditions, 1 hr of leaf wetness is all that is required for infection to occur. Symptoms may take 3–10 days to display.

Management of this disease includes:

- cutting out infected sites on the stem or removing infected plants
- minimizing infection by adjusting the greenhouse environment to eliminate free water on the plants
- cutting surfaces cleanly at the nodes, fruit stalks, etc. to encourage early healing of the wounds.

Penicillium Stem Rot (*Penicillium oxalicum*)

This disease can cause extensive plant death. Disease symptoms are similar to those of grey mould and gummy stem blight, but differ by producing a bluish-grey fungal growth that is usually visible at the lesions. These lesions may occur anywhere along the stem, but are commonly seen at the base of the plant

(10–15 cm above the block) and/or 1.0–1.5 m from the ground.

The disease usually attacks a pruned node and the infected tissue may extend 10–15 cm above and below the infected node. Extensive internal tissue rot results in death of the plant above the infected point. Remove the infected tissue up to 1–2 nodes below the infected node to allow a new sucker to develop [*Plate* 51].

Cultural practices, especially during the plant raising stage, are critical in minimizing or eliminating the disease incidence:

- grow transplants under high light, low RH or high VPD (0.6–0.8 kPa)
- feed with a nutrient solution with a high EC and keep the media a bit on the dry side
- adjust the greenhouse environment to minimize or eliminate free water on the plants and maintain a higher VPD (0.6–0.8 kPa)
- prune with a sharp knife that is frequently disinfected to minimize disease transfer.

Leaf Spots

Several air-borne fungi, including species of *Alternaria* and *Colletotrichum* (Anthracnose) may cause round areas of dead tissue on cucumber leaves [*Plate* 52]. In severe cases, the spots may enlarge, grow together and destroy the total leaf surface. Downy mildew fungus causes somewhat similar spots, frequently in crops planted in August and September. Downy mildew, however, usually attacks the lower leaf surfaces and can be identified by the purplish spore growth it produces.

All of the above-mentioned leaf spots are most severe in areas within the greenhouse where there is poor air movement and high humidity. Fall crops are more prone to attack, especially when "sweating" occurs due to cold nights following warm, humid days.

Powdery Mildew (*Podosphaera xanthii* (formerly *Sphaerotheca fuliginea*))

This is one of the most common and serious diseases of greenhouse cucumber crops. All Ontario greenhouse cucumber growers experience incidences of powdery mildew during the cropping cycle. The first symptoms are small white powdery spots that appear on the upper surface of the leaf. These spots rapidly expand and spread to other leaves and can quickly cover the whole leaf and even the stem and fruit in severe cases [*Plate* 53].

Dry greenhouse conditions tend to promote the spread of the disease through sporulation, whereas free water on the leaf surface increases the rate of infection.

It is difficult to use chemicals to control powdery mildew as the disease rapidly becomes resistant. Use powdery mildew tolerant cultivars to manage this disease. Applying water to the leaf surfaces, i.e., washing down the crop with water, helps decrease the disease incidence, but may increase the incidence of other fungal diseases such as gummy stem blight and *Botrytis*. This should only be done when rapid drying is assured.

Downy Mildew (*Pseudoperonospora cubensis*)

This is a common problem in fall cucumber crops and is prevalent in greenhouses with inadequate ventilation. Symptoms are angular, light green areas, bordered by leaf veins, which turn yellow. A purplish fungal growth may be seen on the under surface of the leaves.

Adjust the greenhouse environment to increase air movement and minimize free water on plant surfaces.

Fusarium Root and Stem Rot of Cucumbers (*Fusarium oxysporum* f. sp. *radicis-cucumerinum*)

This is a relatively new disease in Ontario greenhouses. The upper leaves of the plant wilt and plant vigour declines. The base of the stem is initially tan, eventually turning white, then light salmon. Lesions extend at least 20–30 cm upwards, and may girdle the stem [*Plate* 54]. Roots of affected plants remain firm in contrast to Pythium root rot where the roots become mushy.

This fungus may colonize rockwool blocks. Greenhouse sanitation is the key in minimizing infestations. Implement precautions similar to bacterial canker in tomatoes (p. 78) to prevent widespread incidences. (See OMAF Factsheet *Fusarium Stem and Root Rot of Greenhouse Cucumber*, Order No. 01-081.)

Cucumber Diseases Caused by Bacteria

Bacterial Wilt (*Erwinia tracheilphila*)

Symptoms are a sudden collapse of the entire plant, or sometimes one or several leaves may wilt first. There is no recovery. The striped and spotted

cucumber beetles are the vectors of this disease. The bacteria live in the gut of the beetles and infect the plant once the beetles feed on it. Upon entering the plant, the bacteria reproduce rapidly in the plant's vascular tissues, producing gums that eventually block the vascular tissue, resulting in the collapse of the plant.

To control bacterial wilt:

- control the cucumber beetle by treating vegetation outside the greenhouse and isolating infected plants
- work in infected areas last
- disinfect all pruning and harvesting tools regularly.
- screen the vents against the beetle.

Cucumber Diseases Caused by Viruses

Cucumber Mosaic Virus (CMV)

This is a common problem in greenhouse cucumber production in Ontario. It is usually associated with aphid infestation (especially when fall crops are planted). The virus has a wide host range and aphids are one of the key agents of infection. Cucumber beetles can also spread this virus. Infected leaves and fruit display a light and dark green mottling. The plant tends to lose vigour (thin, spindly growth, weak flowers and abortion of newly formed fruit), and may eventually die [*Plates* 55, 56]. A sudden wilt of whole cucumber plants may occur and is considered a result of a combined infection of CMV and *Pythium*.

To control infection:

- eliminate or minimize the inoculum source (alternative hosts) near the greenhouse
- screen greenhouse vents to prevent aphid invasion
- spray the greenhouse vicinity to decrease aphid populations.

Cucumber Necrosis Virus

This virus is soil-borne and of relatively minor importance in cucumbers. Initial symptoms are pinhole spots in young leaves [*Plate* 57]. These spots enlarge and coalesce to produce large brown necrotic areas that resemble symptoms of a fungal disease [*Plate* 58]. Symptoms tend to be less visible during summer conditions. This virus is transmitted by a soil-inhabiting fungus, *Olpidium radicale*, that appears to infect only cucumbers and its relatives. Once a plant is infected, infection can spread by contaminated hands and tools that come into contact with wounds of uninfected plants. This virus is not known to be seed or aphid-transmitted.

Management measures for this virus include:

- disinfection of nutrient solutions in recirculating systems
- removal and destruction of infected plants
- disinfection of hands and tools during cultural operations such as pruning, harvesting, etc.
- working in infected areas last
- steam sterilization of soil for soil-grown crops.

Also refer to management procedures for *Pepino Mosaic Virus* in Tomato, p. 80.

Pseudo Yellows Virus

This virus is spread by the greenhouse whitefly. Symptoms are chlorotic yellowing between the veins of older leaves and interveinal yellow spotting on intermediate leaves [*Plate* 59]. Upper leaves may remain unaffected during the early stages. Diseased plants become less productive.

Watermelon Mosaic Virus

Symptoms include distortion of the terminal growth, interveinal blister-like protrusions on the older leaves and severe distortion and bump-like protrusions on the developing fruit. The sources of infection are not yet fully identified, but other plants (e.g., alfalfa and certain weed species) are suspected of harbouring the virus. It can be aphid transmitted.

Cucumber Physiological Disorders

Nutrient Deficiencies and Toxicities

A shortage of one or more of the major or minor elements necessary for plant growth may produce symptoms that resemble disease. One of the more commonly occurring deficiencies is magnesium, where certain cucumber cultivars develop areas of lighter green colour in the mid-section of the plant. This symptom is most pronounced on the older, fully developed leaves. Younger leaves near the tops of the plants and on suckers remain a normal green colour. Although the symptom may cause concern, especially to new growers, magnesium deficiency is seldom serious.

Calcium deficiency is a common problem in cucumber production, especially in the younger, rapid-

growth stage [*Plate* 60]. The upper leaves are rounded and cupped downwards and may have light brown-yellow discoloured edges. The growing point dies in severe cases. To minimize this problem, increase the supply of calcium in the fertility program in the early stages of the cropping cycle.

Occasionally, deficiencies of one or more of the minor elements may occur, especially when plants are grown in rockwool or other artificial media. If adequate amounts of minor elements are not included in the feeding solution, iron deficiency may occur [*Plates* 61, 62]. Manganese deficiency has also been noted on occasion.

Toxicity symptoms may also occur if one or more of either the major or minor elements is supplied in excess. Severe toxicities usually result in a burning out of leaf tissue. If deficiencies or toxicities are suspected, send leaf samples for tissue analysis. Damage due to pesticides may also occur.

Peppers

Pepper Diseases Caused by Fungi

The most common greenhouse diseases, *Pythium* and *Botrytis* can affect pepper plants in a manner similar to tomatoes and cucumbers, with similar symptoms displayed [*Plate* 63]. However, the following diseases are specific to peppers and can be problematic in greenhouse pepper production.

Fusarium Stem and Fruit Rot (*Fusarium solani*)

This disease can cause severe economic loss in greenhouse peppers if action is not taken. Early symptoms are lack of vigour, partial wilting of upper leaves on sunny days with slow or delayed recovery. Dark brown sunken lesions are visible on the stems at leaf nodes [*Plates* 64, 65]. Fruit have a more flattened shoulder, longitudinal pale or brown striations, and rot beneath the calyx. (OMAF Factsheet *Fusarium Stem and Fruit Rot of Greenhouse Pepper*, Order No. 01-083.)

Powdery Mildew (*Leveillula taurica*)

This disease is relatively new to Ontario and can be a serious problem. Early symptoms are mottled yellow and light green areas on the upper leaf surface, followed by white, powdery fungal growth on the lower surface. Control measures similar to those for tomato and cucumber powdery mildew are effective [*Plate* 66].

Pepper Diseases Caused by Bacteria

Bacterial Stem Rot (*Erwinia carotovora* subsp. *carotovora*)

Wilting, the first sign of this disease, is caused by the breakdown of the inner stem tissues, which results in a hollow stem. When the disease extends to the bark of the stem, the affected area appears brown and could be mistaken for Fusarium stem rot. Fresh wounds are necessary for infection to occur. Those created by pruning and removing leaves are ideal sites for infection. This disease does not occur on healthy leaves but it can develop in older, dying leaves. Bacteria then enter stems from infected leaves through the vascular system. Bacterial stem rot is favoured by wet, humid conditions. This bacterium is commonly present in soil and also causes soft rot in many field vegetables [*Plate* 67]. It has also been found in the gut of insect larvae and may be spread from infected tissue to healthy plants by adult insects.

This disease is best managed through key measures such as:

- implementing strict sanitation practices
- ensuring the plants are never wet by providing adequate venting and air circulation, and through temperature and humidity controls
- avoiding lush or soft growth through optimum nutrition and watering regimes
- providing adequate time for wounds to heal before sunset.

Pepper Diseases Caused by Viruses

Pepper Mild Mottle Virus

Symptoms of this virus disease on the leaves are usually mild, consisting of mottling and a light or dark green mosaic. By contrast, symptoms on the fruits are usually more noticeable and could include reduced size, distorted shape with distinct raised and sunken areas, and colour streaking [*Plate* 68].

Pepper mild mottle virus (PMMV) occurs worldwide primarily in bell pepper and chili plants. Tomato is not a host. This virus is closely related to tomato and tobacco mosaic virus and therefore has similar properties. It is seed-borne, very stable, and can persist in the environment for at least several months in plant

debris and on surfaces. It is also easily transmitted between plants by contaminated tools and workers' hands.

Using tolerant or resistant cultivars and sanitation measures are the best approach to managing this disease. When an infection is detected:

- carefully remove infected plants in garbage bags without contacting other plants
- restrict entry into infected rows to workers who use coveralls that are laundered daily and gloves that are changed at least daily
- work in infected rows last
- use undiluted skim milk, powdered skim milk (100 g/L water) or a disinfectant for dipping tools and gloved hands while working in the crop.

Also refer to management procedures for *Pepino Mosaic Virus* in Tomato, p. 80.

Tomato Spotted Wilt Virus/ Impatiens Necrotic Spot Virus

Symptoms of these two virus diseases are variable and include bronzing, dark brown spots on young leaves [*Plate* 69], dark brown streaks on stems and leaf petioles, stunted growth, mottled fruit with light green rings with raised centres, and alternate orange or yellow and red bands in ripe fruits. See same disease under Tomato, p. 81.

Pepper Physiological Disorders

Elephant's Foot

The name aptly describes the symptoms. The base of the stem at the point of entry into the growing media is flared, with the outer tissues peeling back, revealing a dark brown-coloured soft rot. The affected plants have a reduced vigour and are more prone to diseases such as *Botrytis* and Fusarium stem rot. Fungus gnats are also attracted to this rotting tissue and may increase the incidence of *Pythium* [*Plate* 23].

This disorder is often seen on plants that were raised under "soft" conditions in the starter house. To manage elephant's foot:

- avoid excessive fertilization, injury to the base of seedlings and overwatering
- provide proper air circulation
- control fungus gnats and other common pests that frequent the growing media.

Blossom End Rot

This disorder is seen at the blossom end of the fruit, as well as on the sidewalls close to the blossom end of the fruit [*Plate* 70]. A grey, water soaked area is an early indication of damage. This area proceeds to become sunken and have a tan to grey colour. Take corrective measures similar to those described for Tomato, p. 81.

Sunscald

This disorder is easily confused with blossom end rot as the symptoms are very similar. Usually sunscald symptoms are seen on the sidewall of the fruit and have a distinct edge, with a dry yellow–tan discoloured sunken area within [*Plate* 21]. This disorder is a result of poor canopy and young fruit exposed to direct sunlight. Increase leaf area to protect the fruit and use shade curtains (if available) or whitewash the exterior roof of the greenhouse to alleviate the problem [*Plate* 22].

Fruit Cracking and Pointed Tip

Internal fruit growth and irregular watering can cause fruits to split. Low temperature regimes may cause fruits to develop pointed ends, degrading fruit quality [*Plates* 71, 72].

Silvering

Silvering occurs on pepper fruit when there is rapid fruit expansion. This may occur in winter as well as in summer. It is believed that during the rapid expansion, the fruit skin separates from the fruit body resulting in the silvering stripes [*Plate* 73]. This is a superficial problem and except in severe cases, the fruit is marketable.

Nutrient Deficiencies and Toxicities

Pepper plants are slow growing and take a long time to display deficiency symptoms of any nutrients that are missing in the fertilizer program. It takes just as long to recover once corrective measures are implemented. It is important that all ingredients for the fertilizer program are included at all times at the appropriate levels. *Plate* 74 and *Plate* 75 are examples of what happens when nutrients are left out of the fertilizer program.

Lettuce

Lettuce Diseases Caused by Fungi

Botrytis and downy mildew are two of the most common diseases that affect lettuce. Greenhouse environment management is key to controlling and managing these problems.

Pythium

This can be a problem in NFT systems if the system is improperly designed, poorly managed (flow rate, solution temperature, aeration) and the plants are overly stressed. The affected plants wilt and have brown discoloured roots that fall apart when handled. The disease can spread rapidly through the production house. Disinfection of the nutrient solution using ultraviolet (UV) lamps works well.

Physiological Disorder

Lettuce Tip Burn

This disorder is commonly seen in greenhouse lettuce production. The usual symptoms are the browning of the edges and tips of the young lettuce leaves. In severe cases they coalesce to cause severe tip burn.

Lettuce tip burn is caused by the lack of calcium translocation to the developing leaves. Any factors that have a positive influence on calcium translocation minimize lettuce tip burn. Increased transpiration increases calcium translocation to the leaf tip, decreasing visual symptoms. Transpiration can be increased:

- through ventilation
- by increasing air circulation around the leaf surface using horizontal airflow fans or turbulators
- by maintaining a slightly greater VPD or lower RH.

Once leaf tip burn symptoms are observed, they do not disappear, and cannot be corrected by sprays, etc. Prevention is the key to eliminating lettuce tip burn.

Russett Spot

This is a problem common to lettuce in storage during shipping and handling. Tan to brown spots appear at the veins of the lettuce and, in severe cases, can coalesce to give an unappealing product. This is caused by too low a storage temperature resulting in chilling injury and may also be caused by ethylene present in the storage facility.

12. Integrated Pest Management

Integrated Pest Management (IPM) for Greenhouse Vegetable Crops

IPM is a pest control philosophy that uses all available control strategies to maintain pest populations of insects, mites, or disease organisms below an economic injury level. It does not advocate a continuous pesticide spray program to "eradicate" pests, but promotes the integration of cultural, physical, biological and chemical control strategies.

The routine spraying of pesticides for "insurance" purposes is no longer likely to achieve effective control. In recent years, this practice has led to a number of problems, which include pesticide resistance, environmental damage, and personal health and safety concerns.

Resistance

Insects can develop resistance to any synthetic pest control product. Developing and registering new pesticides takes significant time and resources. It is essential to use available pesticides as minimally and as efficiently as possible to reduce the development of resistance in pests. Using a combination of management strategies, with pesticides being used only as a last resort, is the best approach to slowing down the incidence of resistance.

Environmental Damage

Concerns over environmental pollution and ground water contamination make it important to reduce the use of pesticides and their misapplication.

Personal Health and Safety

The potential exposure of applicators and workers to pesticides and pesticide residues in greenhouses requires a critical evaluation of frequency of use and pesticide safety during application.

Monitoring

Careful monitoring provides reliable information to guide an integrated pest management program. The most important components of monitoring are sticky traps and crop inspection.

Sticky Traps

The most common greenhouse monitoring technique is using yellow sticky traps (cards or tape) to collect many species of flying insects. These are especially good for adult whiteflies, thrips, leaf miners, fungus gnats and winged aphids. Note that blue sticky traps are especially attractive to western flower thrips. However, if a wide pest complex is present, use yellow traps.

When using sticky cards, it is important to provide adequate coverage. To do this, use a distribution rate of one card every 100–200 m^2. Increase or decrease the rate depending on the size of the operation being monitored, time of year and practical aspects of regular monitoring. Change traps before too many insects make maintaining a weekly record difficult.

Crop Inspection

Another important, and often overlooked, monitoring technique is crop inspection. It is essential for monitoring the presence of plant diseases, mites, wingless aphids, the immature stages of whitefly and leaf miner. Adopt a regular sampling pattern that provides good coverage of the whole greenhouse, including entry points and areas of concern. Again, weekly records are necessary.

Early detection of diseases and sedentary pests (such as aphids or mites) makes control easier and may permit management of a problem with only a spot spray or increased spot application of biocontrol agents.

For successful monitoring, it is necessary to record regularly:

- the date
- crop species and cultivar

- pests identified
- location in the greenhouse
- number of insects trapped
- stage of development (e.g., adults, pupae)
- diseases present or suspected
- control action (pesticide or biocontrols used, rate, area treated, time taken, etc.).

Cultural Controls

Sanitation

Sanitation is the first step in any pest control program. If, due to poor hygiene, a source of infection or infestation is constantly present, pest control programs will be expensive and frustrating. Ensure good sanitation practices in the greenhouse and adjoining structures (boiler rooms, etc.), in the immediate vicinity of the greenhouse, and during every stage of crop production.

Proper greenhouse sanitation is a continual, year-round process. Cleanliness on its own may not control pest problems but it is a basic component of any control program. It is important to:

- remove dead and dying leaves and flowers
- take crop residues far away to be destroyed or composted, and downwind from the greenhouse
- preferably burn residues in accordance with local bylaws or, alternatively, contain and dispose of them
- remove all weeds from inside and immediately outside the greenhouse
- keep walkways clean
- check carefully for pest infestations
- avoid overwintering garden or house plants in the greenhouse, otherwise pests will be maintained for an early invasion of the next crop
- maintain good drainage to eliminate puddles and wet surfaces, as these provide ideal breeding sites for fungus gnats and shoreflies, and are a possible source of infection for diseases
- use a heat treatment to remove pest infestations when the greenhouse is empty between crops. Maintain temperatures at >40°C and humidity at <50% for 3–4 days to control insect and mite pests. This is particularly suitable during the warmer months when these temperatures can be achieved by just closing the vents. *Note: At higher temperatures, plastic fittings may warp.*
- prevent disease organisms from carrying over on empty structures, heating pipes, walks, benches, or equipment by first cleaning and then disinfecting with an appropriate disinfectant such as Chemprocide and Virkon.

See also OMAF Factsheet *Sanitation Recommendations for Management of Insect and Mite Pests of Greenhouse Vegetables*, Order No. 94-029.

Environmental Control

Environmental factors such as light, temperature, humidity, water and nutrients can affect not only the plants, but also the pests and diseases that afflict them. Due to the simultaneous effect environment has on crop production, using environmental control to manage pests is a complex process. Each case is different and needs to be assessed carefully. For example, humidity can play an important role in pest and disease development.

- Spider mites prefer hot, dry conditions. Increasing the humidity by using overhead misting can help retard the development of this pest.
- During the winter, thrips are not particularly mobile. This is probably due to low light levels rather than to low temperatures and it can have implications for monitoring programs. At these times of the year, yellow sticky cards may not catch thrips, even when they are present and actively feeding in the crop.
- Air moisture affects the development of diseases such as powdery mildew and *Botrytis*. This means these problems can be improved using environmental controls.

Weed Control

Control of weeds inside and outside the greenhouse is an important part of any pest management program. Weeds can provide a refuge for insect pests and act as a reservoir for diseases. A 10-m strip of carefully maintained lawn around and between greenhouses will also decrease the danger of invasion by insects and diseases from outside. Use fescue grasses for lawn plantings around the greenhouse as they are the least preferred grasses of western flower thrips.

Herbicide application, cultivation and hand weeding are the most practical methods of controlling weeds in and around greenhouses. However, other, less

labour intensive methods include steaming and soil fumigation.

Herbicides

OMAF Publication 75, *Guide to Weed Control*, contains information on herbicides registered for use in Ontario. Treatments listed in the publication are subject to extensive field trials and observation on farms.

Herbicides may be particularly useful for weed control outside but no herbicides are registered for use inside the greenhouse.

If herbicides are used outside the greenhouse, there is potential for crop damage if any herbicide is used incorrectly. Take the following precautions to minimize spray drift into the greenhouse:

- **Turn off fans to avoid drawing herbicides into the greenhouse**.
- **Close vents before spraying**. Only spray very early in the day to prevent greenhouse temperatures from rising excessively. Delay opening of the vents for at least 30–60 minutes after spraying is completed.
- **Apply herbicides only when wind speed is below 11 kph**. High winds will increase spray drift causing droplets to be carried further away, thereby increasing the chance of drift entering the greenhouse.
- **Use nozzles that minimize spray drift**.
- **Use a sprayer equipped with spray guards**. Guards attached to the nozzle will minimize spray drift and direct sprays to the target.
- **Set sprayer to increase droplet size**. A smaller droplet size will increase spray drift so increasing the size and/or decreasing sprayer pressure will decrease spray drift.
- **If possible, use wipe-on applications**. Drift is minimized and eliminated when this technique is used.
- **Maintain a weed-free environment**. Maintain a 10 m strip of weed-free, short-cropped lawn around the greenhouse to avoid or minimize use of herbicides. Alternative ground covers are landscape mulch and asphalt.

Read the information on chemicals, safety precautions, calibrations, and care and use of sprayers. Where unwanted herbicide residues remain in soil, apply activated charcoal to reduce the problem. The rate varies depending on the type of chemical contaminant and its concentration. A usual range is 0.5–1.5 kg/100 m^2.

See Chapter 1 for more detailed information on precautions with pesticide use.

Resistant Cultivars

Many commercially available cultivars are resistant to diseases. For example, many tomato cultivars are resistant to Fusarium crown and root rot, and several other fungal and viral diseases. Several cucumber cultivars exist with different degrees of tolerance to powdery mildew. To date, no commercial cultivars are resistant to insect and mite pests.

Physical Control

Screening

Screens over vents can greatly reduce the influx of insect pests from outside. In warmer climates where pests occur outside all year, screening is an established part of IPM programs. While not as common in temperate areas, screening is becoming more accepted and its value more apparent.

Screening removes an important variable from a grower's pest management program — the movement of pests into the greenhouse from outside. This includes common greenhouse pests such as thrips, aphids, and whiteflies, but also some less common pests such as tarnished plant bug and European corn borer. These can be major pest problems when pesticide use is reduced (e.g. in biological control programs).

Benefits of using insect screening have been demonstrated in Israel and California. In Ontario, growers who installed screens report reduced numbers of pests, lower pesticide use and improved effectiveness of pest control (especially biological control) measures.

The most important consideration in screening a greenhouse is to determine which pests need to be excluded and its impact on the venting capacity of the greenhouse. The size of the pest determines the mesh size of the screen needed.

Large mesh sizes of the type normally found in household screens are inadequate for excluding most major greenhouse pests. However, they can be useful in keeping out occasional larger pests such as tarnished plant bug and lepidopteran (moth) pests. For smaller insects such as thrips, screens must be of a very fine mesh for total exclusion.

Reduction of airflow is a major concern with screening. Even larger mesh sizes can significantly reduce air movement into the greenhouse.

Increase the intake vent surface area to compensate for the decreased airflow. Forced ventilation/wall vents are much easier and less expensive to screen than top vents. When there are multiple pests of concern, choose the mesh size to exclude the smallest of these pests.

Reduced airflow can lead to overheating of the greenhouse, and stress on the fans (in the case of fan-ventilated greenhouses) that have to work harder to pull the same amount of air through the partially-blocked vent. Address reduced ventilation by increasing the surface area of the screen. In many situations building a screened framework around the vent opening does this. The goal is to ensure that the final surface area of the screens provides sufficient air exchange to allow adequate cooling of the greenhouse.

Several methods are available to determine the increase in surface area of the vents required for any given greenhouse. Important factors are:

- screen mesh size
- fan capacity and
- static pressure drop — the difference in air pressure between inside and outside the greenhouse when the fans are running.

Although software programs exist to help with these calculations, they can be complicated and are generally best left to the screening manufacturers.

The small pore size means that screens are very prone to blockage with dust and other deposits, especially in the summer. Such blockage reduces airflow through the screens and may contribute to excessively high temperature conditions. It is important to:

- clean screens regularly
- make sure easy access for cleaning is incorporated in their design.

Wash screens from the inside with a high-pressure hose. Do not do this when the fans are operating. The water will block the pore openings and completely stop airflow, leading to overheating of the greenhouse.

The effectiveness of the screens depends on their ability to exclude flying insects. Repair tears or holes as soon as possible. Small tears can be simply repaired by gluing a piece of screening over the hole.

The cost of screening depends on several factors:

- the final screening design
- the increase in surface area needed to maintain adequate ventilation
- the cost of the screening material
- whether roof vents or side vents are to be screened
- the frequency of replacement, frequency of cleaning, etc.

For further information, see OMAF Factsheet *Screening of Greenhouses for Insect Exclusion*, Order No. 00-021.

Other Physical Controls

Yellow Sticky Tape

Yellow sticky tape can provide useful additional control of flying insect pests. It works on the same principle as the sticky cards used for monitoring. Place the tape along plant rows or hang vertically within the crop.

Light Traps

Light traps also provide an easy-to-use, non-pesticide alternative tool for reducing and suppressing moth pests such as adults of tomato pinworm and cabbage loopers. Light traps use a combination of black light lamps for attracting insects and a low voltage electrocutor that surrounds the lamps. These lamps emit long wave ultraviolet (UV) radiation around 365 nanometres (nm). They also emit some visible light of wavelengths around 430–540 nm. Ultraviolet light is the most effective part of the light spectrum for attracting night-flying insects, hence their use for attracting nocturnal moths.

Factors to consider with light traps

- **Size:** The size of the traps affects their attractive powers. Most traps have an attracting diameter range of 40–50 m. Larger ones are more expensive.
- **Location:** Ideally, place traps in locations best suited to their attracting range. However, convenience tends to dictate their location and most growers usually place them along walkways. In either case:
  - put a receptacle containing soapy water or a large sticky board below the trap to catch the victims
  - place traps high enough so the light emitted from the trap is not blocked by plants and access by smaller moths is not hindered
  - place just above the plant canopy.
- **Modification of traps:** Increase the trap's efficiency by removing the metallic grid that surrounds the light and electrocution mechanism. Although the grid size is usually large enough to allow small moths such as tomato pinworm adults to fly through, they definitely impede access by larger moths, such as adults of loopers and tomato fruitworms.
- **Time of year:** Light traps are best used during the cooler months of the year when outdoor temperatures are 10°C and less. This eliminates the problem of attracting more flying pests into the greenhouse. However, during the warmer months, place the traps outside of the greenhouse, at a safe distance, to attract adults away from the greenhouse.
- **Maintenance:** To maintain efficiency, inspect and clean the light traps regularly.

Bumblebees

Light traps attract and kill bumblebees. To avoid or minimize trapping of bees in these traps, use a timer so the lights are on at dusk and off at sunrise. Some beneficials may be attracted to the lights. However, lower night temperatures should reduce activity of most of the beneficials at this time, reducing the chances of trapping. Many moth pests, on the other hand, tend to be more active at nights.

Using light traps during the cooler months of the year is a good non-chemical strategy for managing moth pests.

Biological Control

Biological control (biocontrol) is the use of living organisms (such as insects, mites, fungi and bacteria) to control pests such as insects, mites and diseases. Biological control involves more than the release of parasites or predators. A successful program requires planning in advance by at least several months. Consider the following before using biological control.

- Develop a list of resources to help with the program (this may include producers/suppliers of biocontrol agents, other growers, extension specialists, researchers, consultants). Attend courses, seminars, workshops, read magazines and newsletters, and use the Internet to find out as much as possible about biocontrol. Determine what pests need to be controlled and which are the most appropriate natural enemies to use. (See Table 12–1, *Biocontrol Agents for Principal Greenhouse Pests*, p. 95, for a list of biocontrol agents for principal greenhouse pests.)
- If possible, start in a small isolated greenhouse. This allows beginners to focus on one small area and to become more comfortable with using biological control. Subsequently expand the program to include the entire greenhouse operation, thus minimizing chances of economic failure.
- If possible, screen the area to be used. Movement into the greenhouse of pests from outside is unpredictable from year to year, but can swamp a biocontrol program and make it difficult for the natural enemies to maintain control (*Screening*, p. 91).
- Ensure all staff are trained to recognize the pests, biocontrol agents and early symptoms of pest damage.
- Many registered pesticides can have long term (2–3 months or longer) residual impact against natural enemies. Check the pesticide spray records of the previous several months. If such pesticides have been used, then an appropriate length of time must elapse before starting. Use products with less residual impact to control pests

and diseases during this period. Residual effects of many pesticides are listed in Table 12–2 and Table 12–3, p. 96, or are available from biocontrol suppliers.

- Check commercial biocontrol agents to evaluate activity and approximate numbers. The quality of natural enemies produced by the major insectaries is usually excellent, but problems can occasionally arise in shipping. The supplier needs to know about any problems in quality in order to identify and correct problems.
- Follow all instructions in storing and releasing the natural enemies. Many can only be stored for a short period of time under fairly specific conditions.
- Monitor populations of pests and natural enemies, and the progress of the biocontrol program by regularly checking for the following:
  - presence of winged biocontrol agents on sticky cards, especially the parasitic wasps. Be aware that some (e.g. *Eretmocerus*) are highly attracted to yellow and too many sticky cards may be detrimental to the program
  - presence of parasitized insects e.g. whiteflies parasitized by *Encarsia* is detected by black scales and aphids parasitized by *Aphidius* parasitic wasps is detected by mummified aphids
  - presence of non-winged natural enemies by visually inspecting the crop, e.g. predatory mites and immature ladybeetles that do not fly. Inspect the crop, especially in areas of highest pest numbers
  - pest population trends. Monitor pests either on cards or the crop to determine if populations are increasing or decreasing.
- Use compatible pesticides if necessary. Identify such pesticides prior to starting a program so they can be readily used if necessary, Table 12–2 and Table 12–3, p. 96.
- Successful biocontrol programs require patience and experience.

Commercially-produced biocontrol agents are available for all major greenhouse insect and mite pests, but not yet for diseases. For more details about implementing biological control or about supplies of parasites/predators, consult OMAF's greenhouse vegetable pest management specialist or biological control suppliers.

Chemical Control

While pesticides remain an important component of greenhouse pest management programs, monitor their use carefully. For the reasons noted above, make the best use of those available.

Resistance

Resistance can develop to any pesticide used incorrectly or too often. Although there are benefits from new product registrations, do not wait for the latest advance in pesticide chemistry. The long-term problems presented by pesticide resistance far outweigh the short-term gains of a new product if it is used incorrectly.

Resistance is the evolutionary adaptation of a population to survive a pesticide dose that is lethal to most of its individuals. It is an inherited trait, which is passed on to future generations. While resistance does not develop within an individual during its lifetime, it usually exists in a population at very low frequencies (too low to be measured or noticeable). The frequency of resistance increases when pesticide exposure kills susceptible individuals while allowing successively greater numbers of resistant individuals to survive. Because of the immense genetic diversity of arthropod pests, their short life cycles, great reproductive ability and the relatively closed nature of greenhouse production, greenhouse insect and mite pests have great potential for developing resistance. Relying on chemical control inevitably leads to development of resistant populations.

Resistance management programs aim to reduce the pressure applied to pest populations by pesticides. The best approach is to minimize pesticide use by regarding them as a last resort measure only. An effective approach for reducing the development of resistance is to use biological control as the major strategy and integrate chemical controls only when necessary. Cultural measures such as resistant varieties and sanitation must be used. Where applicable, incorporate physical controls such as insect barriers and traps.

TABLE 12–1. Biocontrol Agents for Principal Greenhouse Pests

Pests	Biocontrol Agent
Whitefly *(Trialeurodes vaporariorum or Bemisia argentifolii)*	*Encarsia formosa* (parasitic wasp)* *Eretmocerus eremicus* (parasitic wasp)* *Delphastus pusillus* (predatory beetle)** *Dicyphus hesperus* (predatory bug)**
Spider mite *(Tetranychus urticae)*	*Phytoseiulus persimilis* (predatory mite)** *Feltiella acarisuga* (predatory midge)** *Stethorus punctillum* (predatory beetle)** *Amblyseius californicus* (predatory mite)**
Western flower thrips *(Frankliniella occidentalis)*	*Amblyseius* spp. (predatory mites)** *Orius* spp. (predatory bug)** *Hypoaspis* sp. (predatory mite)** *Atheta coriaria* (predatory beetle)** Nematodes: *Steinernema feltiae***
Aphids: various species green peach aphid *(Myzus persicae)* melon aphid *(Aphis gossypii)*	*Aphidius* spp. (parasitic wasps)* *Aphidoletes aphidimyza* (predatory midge)** Ladybeetles (*Harmonia* and *Hippodamia*) Lacewings
Fungus gnat *(Bradysia and Corynoptera spp.)*	*Hypoaspis* spp. (predatory mites)** Nematodes: *Steinernema* sp.** *Bacillus thuringiensis* (bacterium sold as Vectobac) *Atheta coriaria* (predatory beetle)**
Caterpillars *(cabbage loopers, European corn borers)*	*Bacillus thuringiensis* (bacterium sold as Dipel, Foray etc.) *Cotesia marginiventris* (parasitic wasp) *Trichogramma* spp. (parasitic wasps)*
Leafminer *(Liriomyza spp.)*	*Diglyphus* sp. (parasitic wasp)* *Dacnusa* sp. (parasitic wasp) *

* Parasite: usually requires only one host for completion of development, often killing it by living on or in its body.
** Predator: feeds on its prey (pest) by catching them, but otherwise lives independently of them.
It must consume more than one individual to reach maturity.
Caution is required when using pesticides along with biocontrols since most pesticides are harmful to natural enemies. Applying just one harmful pesticide can prevent any further use of biocontrol agents for an extended period of time. See Table 12–2 and Table 12–3, p. 96.

Note that when pesticides are used in an IPM program, the rate at which resistance develops increases if one class of pesticides (e.g., organophosphate, synthetic pyrethoid, carbamate) is used for a prolonged period. To slow the rate of resistance development, it is necessary to rotate pesticide classes every few weeks, or for a period equal to the generation time of the pest being controlled (Table 14–1, *Insecticide and Miticide Toxicity and Classification*, p. 123).

Everyone in the industry must use pesticides responsibly so that new products do not lose their effectiveness within a year or two of registration.

Pesticide Application

The most common cause of control failure is not resistance. Several other factors determine the effectiveness of a particular pesticide application.

- Ensure accurate calculation and measurement of pesticide rates.
- Proper coverage is needed for good pest control. Simple changes such as walking more slowly through the crop, or walking every aisle instead of every other one, significantly improve performance.
- Maintain spray equipment in good condition. Replace spray nozzles regularly. Older nozzles become worn, which can alter spray pattern and droplet size.

TABLE 12-2. Reported Effects of Registered Insecticides/Miticides on Biological Control Agents[a,b,c]

Insecticides	*Encarsia formosa* + *Aphidius*	*Phytoseiulus persimilis*	*Amblyseius cucumeris* + *Hypoaspis*	*Aphidoletes aphidimyza*	*Orius* spp.
Ambush/Pounce	H (56-84)	H (56-84)	H (56-84)	H (56-84)	H (56-84)
Avid	H (21)	H (14)	H (14)	H (21)	H (21)
Confirm	S	I	S	—	I
Diazinon or Basudin	H (28-42)	H (7)	H (7-21)	H (42-56)	H (30)
Dibrom (F)	H (7)	H (3-7)	H (3)	H (7)	H (3)
Dipel/Foray	S (0)	S (0)	S (0)	S (0)	S (0)
Dyno-Mite	H (>28)	H (7)	H (28-36)	H (>28)	H (28-35)
Floramite	—	I (7)	—	—	S
Intercept	S	S (0)	S (0)	S	H (28-42)
Insecticidal Soap	H (0)	H (0)	H (0)	H (0)	H (0)
Malathion	H (56-84)	H (7-14)	H (56-84)	H (14-70)	H
Nicotine (F)	I (3)	H	H (1-7)	H (1-7)	I
Thiodan	H (56-84)	H (4-14)	H (42-70)	H (56-84)	H
Vectobac	S	S	S	S	S
Vendex	S	S	S	S	S

a Numbers in parentheses refer to residual toxicity to biological agent, in days, where reliable data exists. S = Safe; H = Harmful; I = Intermediate; "—" means no data is available, so *presume toxic unless otherwise proven*

b This table serves only as a guide to possible effects of pesticides. *Variations in toxicity may occur under varying conditions.*

c This table was compiled from information produced by *Applied Bionomics Ltd., Koppert Biological Systems, and Biobest Biological Systems.* Where discrepancies existed in the available information, it provides a range of residual toxicities or the more conservative figure.

TABLE 12-3. Reported Effects of Registered Fungicides on Biological Control Agents[a,b,c]

Fungicides	*Encarsia formosa* and *Aphidius*	*Phytoseiulus persimilis*	*Amblyseius cucumeris* + *Hypoaspis*	*Aphidoletes aphidimyza*	*Orius* spp.
Benlate	S (0)	H (14-21)	H (14-21)	S (0)	S (0)
Botran	S	S	S	S	
Decree	—	I	—	—	I
Maestro/Captan	S (0)	S (0)	S (0)	S (0)	S (0)
Manzate	S (0)	S (0)	S	H	S (0)
Mycostop	S	S	S	S	S
Nova	S	S (0)			S (0)
Previcur	S (0)	S (0)	S	—	I
Ridomil Gold	S	H	I	—	—
Rootshield	S	S	S	S	S
Rovral	S (0)	S (0)	S (0)	S (0)	S (0)
Sulphur	H (>28)	S (0)	I	I	S

a Numbers in parentheses refer to residual toxicity to biological agent, in days, where reliable data exists. S = Safe; H = Harmful; I = Intermediate; "—" means no data is available, so *presume toxic unless otherwise proven.*

b This table serves only as a guide to possible effects of pesticides. *Variations in toxicity may occur under varying conditions.*

c This table was compiled from information produced by *Applied Bionomics Ltd., Koppert Biological Systems and Biobest Biological Systems*. Where discrepancies existed in the available information, it provides a range of residual toxicities or the more conservative figure.

- Consider different application technologies. High-volume, low-volume, and electrostatic-spray application all have their place in the greenhouse for appropriate purposes.
- The biggest improvement comes with effective timing and targeting of sprays. A scouting program can provide the information required to decide when, where, and why a pesticide application is needed. Sprays can then be applied where most needed (e.g., as spot sprays), when they will provide optimal control, and directly at the appropriate pest at the correct life stage.
- Pesticide effectiveness varies, often considerably, from greenhouse to greenhouse, depending on factors such as the usage history of a particular product, the method of application, the time of application, and the water quality. Adjust water pH to 5.5–6.0; at pH >7, the pesticide may degrade rapidly.

Pesticide Compatibility

- Before mixing pesticides, read the product labels carefully for compatibility statements or contact the supplier.
- Avoid mixing EC formulations.
- Never mix herbicides with fungicides and insecticides; apply herbicides with spray equipment reserved for herbicide use only.

13. Insect and Mite Pests

Thrips

Description and Life History

Thrips are tiny, slender, agile insects about 1.5–2 mm in length when fully developed. Adults vary in colour from dark brown or black through to yellow or straw brown. Immatures are usually white or yellow with red eyes. Several thrips species are found in the greenhouse, including eastern flower thrips, onion thrips, and western flower thrips (WFT) [*Plate* 76].

All thrips have a similar life cycle. The adult female lays tiny white eggs in developing leaves. The eggs hatch in 5–7 days, and the white larvae emerge to feed on the leaves and petals. They pass through 2 larval stages, a prepupal stage and a pupal stage (on the soil or plant) before becoming adults. Adults can live up to 7 weeks. A new generation may occur every 20–35 days, depending on the temperature.

Damage

Piercing/sucking mouthparts cause white streaked areas on leaves and fruits or translucent spots on flower petals. Feeding is characterized by tiny, black, fecal deposits on leaf surfaces. Adult females can also damage fruit quality (e.g., of tomatoes) by laying eggs in the fruit. Small whitish "ghost-spots" appear where eggs are laid, which cause uneven fruit ripening [*Plate* 77].

Thrips also rapidly develop pesticide resistance. They can carry impatiens necrotic spot virus/tomato spotted wilt virus (INSV/TSWV), which can devastate many common greenhouse crops [*Plate* 78]. Proper diagnosis is essential, as these viruses have a wide host range and produce a wide variety of symptoms. Control of INSV/TSWV is difficult, involving thrips population management, removal of infected plants, and good weed control. Use of indicator plants such as petunia or fava bean can be a useful means for early detection of INSV/TSWV.

Control Strategies

Employ a regular monitoring program using yellow or blue (both very attractive colours to WFT) sticky cards and regular crop inspection.

All stages of the thrips (except eggs) can be detected by tapping buds or flowers over a sheet of white paper.

Biological Control

- Several biological control agents are available for thrips control: the predatory mites *Neoseiulus (Amblyseius) cucumeris, Neoseiulus (Amblyseius) degenerans,* and *Hypoaspis;* the predatory bug, *Orius insidiosus;* and the predatory rove beetle, *Atheta coriaria.*
- Best control is obtained by using more than one in combination. Introduce biocontrols when pest levels are low, using a sufficient quantity to achieve success.

Neoseiulus (Amblyseius) cucumeris — This buff-coloured predator feeds mainly on the first nymphal stage of thrips.

- *Neoseiulus (Amblyseius) cucumeris* is usually shipped to growers in a mixture that includes bran and bran mites. The bran provides food for the bran mites, which are themselves food for the predatory mites. The bran/mite mixture is available in small sachets or in containers from which the mixture is sprinkled directly onto the crop. The sachets serve as small rearing units from which predatory mites emerge over several weeks.
- Always examine the bran mixture prior to use. The bran should not be mouldy or smell of ammonia, and live predatory and bran mites should be visible.
- Healthy predatory mites move rapidly, whereas bran mites move more slowly. Hang sachets in sheltered positions to minimize dehydration of the bag contents. Rates of application of this predator vary with crop and level of thrips infestation. Contact the biocontrol supplier, consultant or OMAF IPM Specialist for suggested rates.

Neoseiulus (Amblyseius) degenerans — This predator differs from *N. cucumeris* in appearance and in being able to tolerate less humid conditions.

- It is dark, very agile, and reproduces very well on pollen.
- It can be reared on Castor bean plants, which may be used as release points for the predator within the greenhouse.
- It performs best in situations where it has a pollen source to encourage establishment (e.g. greenhouse peppers).

Hypoaspis — This soil-dwelling mite provides additional thrips control by feeding on pupae in the crop media. For more details, see *Fungus Gnats/Shore Flies*, p. 113.

Orius insidiosus — *Orius insidiosus*, the minute pirate bug, is a winged predator that consumes all mobile stages of thrips. Adults are black with white and cream markings on the wings. The youngest nymphs are yellow, while the oldest ones are a dark, mahogany brown.

- *Orius* also feeds on pollen, spider mites, aphids, whiteflies, moth eggs, and young caterpillars. However, its preferred food source is thrips.
- Pirate bugs are sensitive to day length and should not be released in greenhouses before mid-March unless one can provide at least 13 hr of light.

Atheta coriaria (rove beetle) — This soil-dwelling beetle was originally developed for control of fungus gnats and shoreflies, but also feeds on thrips pupae in the soil. For more information, see *Fungus Gnats/Shore Flies*, p. 113.

Chemical Control

Chemical control of WFT can be difficult because they tolerate most pesticides and feed deep within the flower or on developing leaves. This makes them a difficult target for insecticides, so thorough coverage is essential. General recommendations regarding pesticide use for thrips control are as follows:

- If available, rotate chemical classes and use a single chemical class only for the duration of the thrips' life cycle. This generally means using a different class every 2–3 weeks depending on time of year. Generation times are longer at cooler temperatures.

- It is best to apply pesticides in early morning and late afternoon, when flight activity of thrips is at a peak. This increases exposure of the thrips to the pesticides.

Whiteflies

Description and Life History

Adult whiteflies are small, winged, white insects about 1.5–2 mm long. They lay eggs on the underside of the youngest leaves and are too small to be seen clearly without a microscope. A female whitefly may lay up to 300 eggs during her lifetime and can live up to 2 months. The nymphs or crawlers hatch in 5–10 days, are flat and scale-like, and crawl around for a short while before becoming immobile.

Adults emerge after 3 nymphal stages and 1 pupal stage. Old pupal skins and adults may be found on the underside of lower leaves, which may have symptoms of wilt. On average, the whitefly completes its life cycle in 35 days at 18°C and in 18 days at 30°C. Whiteflies have no special overwintering stage and can usually survive as long as some kind of plant life is around [*Plate* 79].

Species of Whiteflies

Two whiteflies concern growers in Ontario: the greenhouse whitefly (GWF) and the silverleaf whitefly (SLWF). The GWF and SLWF adults look very similar, albeit with some differences:

- The SLWF is slightly smaller than GWF, and its body is more yellow.
- At rest, SLWF holds its wings tent-like above its body, while the GWF holds them flatter and more parallel to the surface on which it is resting.
- The major diagnostic differences between GWF and SLWF appear in the pupal stages. The GWF pupa is raised off the leaf surface and is surrounded by a fringe of hairs, while the SLWF pupa sits flat on the leaf and does not have a fringe. These features are best seen with a microscope.
- SLWF fly in a more direct manner, while the GWF assume a more haphazard flight pattern.
- The life cycle of SLWF takes longer to complete.
- SLWF is less adapted to cold conditions.

Damage

- Piercing/sucking mouthparts allow them to remove sap from the plant, reducing plant vigour.
- Whiteflies excrete large amounts of a sugary substance called honeydew. Honeydew promotes the growth of a black sooty mould fungus on leaf and fruit surfaces, reducing photosynthesis and fruit quality respectively. The sooty mould itself does not damage the plants.
- Whiteflies can transmit viruses. For example, the SLWF is reported to transmit over 60 viruses, and the GWF has been associated with the spread of beet pseudo-yellows virus in cucumbers.

Control Strategies

- Implement a routine monitoring program using yellow sticky cards and plant inspections.
- Use host plants more attractive to whiteflies than the main crop as an early detection tool or as a trap plant. Plant species such as eggplant and fuchsia can be used for these purposes.
- Identify the whitefly species present on the crop.
- React promptly to the presence of whitefly adults either on cards or on terminal leaves.
- Maintain good weed control inside and outside the greenhouse.

Biological Control

- Two parasitic wasps are commercially available for whitefly control: *Encarsia formosa* and *Eretmocerus eremicus*. *Encarsia formosa* is more effective against GWF, but provides some control against SLWF. *Eretmocerus* is more effective against SLWF, but also provides good control of GWF. Two predators are also available commercially, a small, black beetle, *Delphastus pusillus*, and a predatory bug, *Dicyphus hesperus*.
- Good sanitation, weed control, and low whitefly numbers to begin with, are essential for successful biological control of whitefly.

Encarsia formosa — Adult wasps about 0.6 mm long, suppress whitefly populations mainly by laying eggs into the immature stages or scales. Adult *Encarsia* can live for a few days to a month depending on the temperature. Females lay 50–350 eggs in their lifetime. A greenhouse whitefly scale turns black 10–14 days after being parasitized. On average, the adult wasp emerges 2 weeks later. When the adult develops fully, it cuts an opening in the top portion of the black scale before emerging. Parasitized SLWF turn tan-brown and are less easily noticed. For biological control of SLWF, consider higher introduction rates. To use *Encarsia* successfully:

- avoid pesticides with long residual effects for at least 3 months before the initial release
- monitor the crop for whitefly presence at all production stages and follow population level trends. This permits you to place and time parasite releases more accurately
- introduce *Encarsia* at first sign of whitefly, or preventively before whiteflies are detected. If whiteflies are present before you release Encarsia, knock back populations with a low-residual pesticide
- avoid using *Encarsia* between December to February without adjusting light and temperature conditions to suit the parasitoid
- distribute *Encarsia* in shaded parts of the plant where the parasites are protected from direct sunlight
- distribute cards relatively evenly, but place more in areas where whiteflies have been observed. You can achieve more distribution points by purchasing cards with fewer parasitized scales per card
- do not remove leaves with immature parasitized scales during deleafing or pruning operations in vegetable crops such as tomato. Such removal slows build-up of *Encarsia* numbers and parasitism rate
- continue introducing *Encarsia* until at least about 80% of the scales on older leaves are black. During warmer months when whiteflies migrate into the greenhouses, you may need to maintain or increase introductions

Eretmocerus eremicus — Adults are about 0.6 mm long and yellow. They lay eggs under the whitefly larvae (preferably 2nd or 3rd stage). This wasp has a sex ratio of 1:1 (male:female). Introduction rates refer to the number of *females* introduced. This is different from *Encarsia*, where all individuals are female. Like *Encarsia*, mortality of whiteflies can be caused by parasitism and by host feeding. The parasitized whitefly pupa is a yellowish-brownish colour (both GWF and SLWF).

Delphastus pusillus — *Delphastus* is a predatory beetle. Both adult and larval *Delphastus* feed on whiteflies, particularly on the eggs and nymphs. *Delphastus* are reported to avoid parasitized scales, feeding on principally the non-parasitized scales. This behaviour makes *Delphastus* compatible with *Encarsia*. Use these beetles to supplement the activity of *Encarsia* in reducing whitefly populations. Adult *Delphastus* live for 6–9 weeks. They are reported to require a minimum diet of 10 whitefly eggs/day to reproduce. These beetles are reported to work well on cucumber but not tomato crops.

Dicyphus hesperus — *Dicyphus* is a predatory bug with piercing/sucking mouth-parts. These bugs are general feeders but they appear to have a preference for whiteflies, feeding particularly on the eggs and larval stages. To a lesser extent, they will feed on aphids, spider mites, thrips, leafminer larvae, and moth eggs. In the absence of prey, a high population of *Dicyphus* may cause damage to tomato fruits. For management of whiteflies, it is best to use *Dicyphus* in conjunction with the parasitic wasps, *Encarsia formosa* and *Eretmocerus eremicus*.

Physical Control

Sticky Traps — Use yellow sticky traps in various forms to trap large numbers of adult whiteflies. Large, yellow sticky boards or 30 cm yellow sticky tapes can be placed in "hot spots" at a rate of about one per plant. Alternatively, hang yellow, sticky tape between posts along plant rows. Such tapes will also trap fungus gnats, shoreflies, *Aphidius* spp., and *Encarsia*, especially under low whitefly populations. Be careful in using large quantities of sticky tape in conjunction with parasitoids, especially with *Eretmocerus* which is highly attracted to the colour yellow.

Vacuuming — Hand vacuuming of adults in "hot-spots" is a very effective way to rapidly remove adult whiteflies.

Insect barriers — Installing fine screens over vents and doorways will significantly reduce movement of outdoor populations into greenhouses. Where whiteflies move in from adjacent field crops (e.g. field tomatoes) in large numbers at certain times of the year (e.g. during harvest), consider screening as a first line of defence.

Chemical Control

- Whiteflies have developed resistance to many pesticides. Judicious use will extend the effective life of pesticides while delaying the build-up of resistance.
- Rational and judicious pesticide use requires a regular monitoring program, using action thresholds, rotating chemical classes, and incorporating the use of all available non-chemical control strategies.
- When using a systemic insecticide, ensure that it is applied correctly. The root system should be well developed and the plant actively growing. Limited watering 12–18 hr before application assists in better uptake and effectiveness.

Two-Spotted Spider Mite

Description and Life History

The two-spotted spider mite (TSSM) attacks many greenhouse crops. The 8-legged female adult is approximately 0.5 mm long with a rounded abdomen. The male is distinguished from the female by its smaller, narrower body and pointed abdomen. Adults range from pale yellow to orange to brown. The overwintering or diapausing stage is reddish orange. Day lengths of 12 hr and less, decreasing temperatures and a deteriorating food source will induce diapause in spider mites. During diapause, spider mites can tolerate very low temperatures. A short spell of heating is not sufficient to break its diapause.

Close examination of leaf undersurfaces shows mites to be very tiny moving dots. The 2 dark spots on the body of TSSM are the gut contents showing through the transparent body. After mating, each female mite lays about 6 pearly-white eggs/day. Over an average lifetime, a female lays 100 or more eggs on the undersurface of foliage. Newly hatched mites pass through the typical 6-legged larval stage and 8-legged protonymph and deutonymph stages. The last of these is an immobile resting stage, hence a very difficult target for miticides. The life cycle from egg-adult ranges from 23 days at 15°C to just 4 days at 32°C. Development is fastest under hot, dry conditions [*Plate* 80].

Damage

- All active stages of the two-spotted spider mite feed by piercing the lower epidermis of the leaf with sucking mouthparts.
- The feeding injury starts as a yellow "stippling". As mite numbers increase, the entire leaf appears stippled or light-coloured on the upper surface. Very heavily infested leaves become yellow and brittle, with obvious webbing on the leaves.
- If infestations proceed without control measures, plants may be killed. Mite populations seem to explode at certain times of the year, since the life cycle varies considerably with temperature.
- Other factors, such as humidity and plant nutrition are important, and can be used to help reduce mite outbreaks.

Control Strategies

Conduct a proper cleanup between crops to reduce initial infestations in subsequent crops. Do this just before the overwintering or diapausing phase of the spider mites, because the diapausing mites hibernate in the ground, hollow stems, pipefittings, cracks, and crevices during the fall and winter months. The mites become active again during late winter and early spring. The red mite stages are generally pesticide-resistant and are not as readily fed upon by predators. When the red post-diapausing mites are detected, use low residual sprays on lightly infested leaves, and remove and destroy more heavily infested leaves.

Biological Control

- The principal biological control agent available for spider mites is the predatory mite, *Phytoseiulus persimilis*.
- Other biological control agents include the predatory mites, *Amblyseius californicus* and *A. fallacis*, a ladybeetle, *Stethorus punctillum*, and the predatory mosquito-like midge, *Feltiella acarisuga*.

Phytoseiulus persimilis — This predatory mite is about the same size as TSSM, but is pear-shaped, pale salmon to bright orange, does not have the 2 spots, and moves more rapidly on long legs. It feeds specifically on spider mite and does not hibernate.

- Without spider mites, the predators die and new introductions are required. Adult predators feed on about 7 adults or 15–20 eggs per day. At 20°C, *P. persimilis* almost doubles the reproductive rate of the pest. Control with *P. persimilis* is best between 20°C–26°C. Above 30°C and at humidities under 60%, these predators do not thrive, and seek cooler, more protected areas lower down in the crop canopy. In contrast, TSSM thrive under these conditions. Predators are available commercially either mixed with vermiculite or on bean leaves. With either carrier, treat infested plants at first sign of damage. Before releasing the predators, always ensure that they are alive and very active and try to place a few predators onto every infested leaf.

Amblyseius californicus* & *A. fallacis — These predatory mites are amber-coloured and droplet shaped, very similar in appearance to *N. cucumeris*. Like *N. cucumeris*, they attach whitish oval eggs to hairs along the veins of the undersides of leaves. They can feed on other mites such as the carmine spider mite, and can survive on pollen. They are also reported to tolerate high temperatures, low humidities and a range of pesticides.

Stethorus punctillum — This is a tiny, oval, convex, shiny black ladybeetle. It lays white eggs singly on the undersides of leaves. The eggs turn blackish just before the larvae hatch. Newly-hatched larvae are grey to blackish and have many long branched hairs. Just prior to pupation, the entire larva turns reddish. Pupae are black and flattened, and the entire body is covered with yellow hairs. Newly emerged adults are reddish-orange for a few hours and then turn black. *Stethorus punctillum* is strictly a predator of plant-feeding mites and prefers the egg stage. It is reported to establish on pepper and cucumber crops, but not on tomato crops.

Feltiella acarisuga — This predatory midge, also known as *Therodiplosis persicae*, resembles mosquitoes. The adult is able to fly and actively search for spider mites. It lays eggs alongside spider mite colonies. Orange-coloured larvae hatch from the eggs and can feed on all stages of spider mites. Larvae pupate next to the leaf veins in white cocoons. The life cycle varies with temperature, taking 2–4 weeks to complete. *Feltiella* will feed on red diapausing mites on which *Phytoseiulus* will only reluctantly feed. Establishment, though variable, has been reported to occur on all greenhouse crops including tomato under suitable conditions. *Feltiella* performs best under high humidity (>80% RH) conditions and in 'hot spots'. Note that use of sulphur can reduce the efficacy and survival of *Feltiella*.

Physical Control

Misting plants and maintaining relatively high humidities help suppress spider mite populations. For example, at 20°C and 36% RH, female TSSM will lay about 7 eggs per day; at 95% humidity, about 30% fewer eggs are laid.

Chemical Control

Because of their great reproductive potential, two-spotted spider mites easily develop pesticide resistance. To effectively manage this pest using pesticides, observe these guidelines:

- Direct sprays to the underside of leaves where spider mites usually congregate.
- The webs in areas of high mite density can protect the mites and the eggs within and beneath the web. In such cases, use higher spray pressures to penetrate the web.
- Because of TSSM's high reproductive potential, use non-chemical control options as much as possible to minimize the development of pesticide resistance.

Tomato Russet Mites (TRM)

Description and Life History

Plant species known to be hosts of the tomato russet mite (TRM) include tomato, petunia, morning glory, bell pepper, potato, nightshade, tobacco, field bindweed and eggplant. Tomatoes, however, are the preferred host and facilitate profuse development of this mite. Potatoes can also harbour TRM but this crop does not appear to suffer as much damage as tomatoes. Although tobacco is listed as a host, TRM may not reproduce on this species. Unlike most other greenhouse pests, TRM feeds on all green surfaces of the plant, including upper leaf surfaces, and is able to resist direct sunlight. Mites travel on an infested plant by crawling and can move about 1.25 cm in 2 min. When the mites have fed on all the surrounding fresh green tissue, they crawl to the tips of stems, leaves, and hairs, and wait there to grab onto whatever comes along to facilitate their transport to another host. They may also be transported by wind, tools, and clothing.

Adults are yellowish-orange in colour, cone-shaped, and have 2 pairs of legs. Adult females, which are the largest of the stages, are 200 microns or less than 0.25 mm long, and 50 microns thick. Females each lay about 10–53 eggs among the hairs or in tiny crevices on the surfaces of stems, leaves and fruits. Adult females live for approximately 2–3 weeks and produce a generation in about 7 days under greenhouse conditions. Damage by these mites is the result of feeding on the outermost layer of cells on the plant surface. Damage to these cells, followed by their oxidation, results in the bronzed appearance. Typically, damage starts on the main stem at about the base or mid-level of the plant and spreads upwards.

The TRM does not produce any special hibernating forms to survive winter conditions. Growth and survival depend on the availability of green tissue. Reproduction is continuous as long as conditions are favourable. Laboratory experiments have shown that adults and some eggs will survive for at least 10 days when exposed to a constant temperature of 1°C, whereas exposure to a constant temperature of -5°C resulted in 100% mortality after 4 days.

Damage

The TRM is probably the least obvious of greenhouse pests, its presence not being easily detected until it has multiplied to very high population levels. The earliest indication of TRM in a greenhouse tomato crop is a subtle bronzing of the stems and leaves [*Plate* 81]. Later symptoms include papery brown leaves and bronzed, russetted (with many small cracks) fruits. The mites are rarely found in flowers and usually do not injure them. The mites themselves are not easily seen and a minimum 20× magnification lens is required to see them. By the time TRM damage is observed in a crop, many neighbouring plants would also have accumulated significant populations despite the lack of apparent damage symptoms.

Control Strategies

Monitoring & Early Detection

Carefully check plants for feeding symptoms. Once detected, the grower can take appropriate measures that could include roguing or plant removal.

Cultural Control

A very important management strategy for TRM is not having any potential host plants in the greenhouse between crops, and in the immediate surroundings of the greenhouse. A thorough cleanup between crops and good weed control inside and outside of the greenhouse will assist in reducing incidence and spread in the greenhouse.

Biological Control

The predatory mite *Neoseiulus (Amblyseius) fallacis* may have potential for managing TRM.

Broad Mites/Cyclamen Mites

The cyclamen mite mainly attacks ornamental crops, but it also attacks field crops and shrubs. Broad mites have a very wide host range as well, attacking a similar ornamental host range as the cyclamen mite, but also crops such as peppers, cucumbers, aubergine or eggplant, potatoes and tomatoes.

Description and Life History

Adult cyclamen mites are the larger of the two species, being 0.75–1.0 mm long, while broad mites are less than 0.2 mm. The adult cyclamen mite varies from milky white to yellowish brown and are elliptical in shape, whereas the broad mite can vary from translucent and colourless to pale brown, with a white stripe down the centre of its back. Adults of both species can be easily mistaken for each other but their eggs are quite distinct. Eggs of the cyclamen mite are about 0.35–0.5 mm long and are oval, opaque white with a smooth surface, whereas those of the broad mite are about 0.08 mm long, flattened and covered with 30–40 whitish bumps.

Optimum conditions for both mite species are 16°C–27°C (60°F–80°F) and 80%–90% RH. They can both complete a life cycle in 1–3 weeks, depending on temperature. Female cyclamen mites begin laying eggs within 2 days after emergence and each female may lay 1–3 eggs per day, for a total of 12–16 eggs during her lifetime. These eggs are laid in moist, dark places, typically within the growing points of vegetable crops. Female broad mites lay 30–76 eggs on the leaf surface over an 8–13-day egg-laying period. No diapause has been reported for both mite species but they appear to overwinter either in greenhouses or outdoors as adults in protected locations.

Both mite species can be similarly spread by windblown infested plant material, human transfer of infested plants, and contact between infested plants. Only male broad mites transport inactive female larvae (quiescent nymphs or pupae) on their backs, usually moving upwards towards the plant's growing points. This arrangement facilitates mating as soon as the adult females emerge. Another major difference between these two species is that broad mites can be spread by whiteflies whereas no such relationship has been reported for cyclamen mites. Broad mites can be spread by attaching to the legs of whiteflies, and to a lesser extent, to their antennae. Studies suggest that this relationship between broad mites and whiteflies is specific and that transport of the broad mites by other pests such as thrips and aphids is insignificant. Studies also suggest that some whitefly species, including those commonly found in greenhouse crops, are more efficient carriers than other whitefly species.

Damage

Damage includes stunting, misshapen leaves on new growth, [*Plates* 82, 83] bronzing of the young stems and leaves, distorted young fruits, whitish or brown streaks on developing fruits, and sometimes, dieback of growing points. At first glance, these symptoms might suggest herbicide drift or even some type of virus.

Control Strategies

Monitoring

Regular monitoring of the growing points of crops is the simplest method for detecting these mites. Any sign of abnormally reduced growth or bronzing on a single plant or a few adjacent plants is a signal for microscopic examination of affected tissues. Generally, these mite species avoid light and this explains why they are found in the growing points. Cyclamen mites can be observed in the young, developing buds, whereas broad mites are more often found on the undersides of young, developing leaves at the growing point. As indicated previously, infestations are usually "clumped," i.e. concentrated on a few adjacent plants, and specifically on new, young growth, gradually spreading out from the initial focus of infestation.

Cultural Control

This entails roguing or removal of infested plant parts, as well removing susceptible host crops and weeds either in the greenhouse or outside its immediate surroundings.

Biological Control

Potential biocontrol agents for the broad mite are *Neoseiulus* (*Amblyseius*) *barkeri*, and *N. californicus*.

Aphids

Description and Life History

Aphids are small (2–3 mm), soft-bodied insects with long legs and antennae. A pair of tube-like structures called cornicles project from the posterior end. Several species may infest greenhouses, with colour patterns ranging between black, grey, red, yellow and green. The species most commonly found in greenhouse crops are the green peach aphid (*Myzus persicae*), the cotton or melon aphid (*Aphis gossypii*) and the potato aphid (*Macrosiphum euphorbiae*). Another species that can be found causing leaf distortion in pepper crops is the glasshouse potato aphid (*Aulacorthum solani*) [*Plate* 84].

Adult aphids are predominantly wingless, although winged adults can develop under conditions of high population density. This adaptation serves as a dispersal mechanism, allowing aphids to move into a greenhouse from outside or to spread rapidly within a greenhouse.

In a greenhouse situation, all aphids are female and give birth to live young. These offspring can reproduce within 7–10 days. One aphid can give birth to 60–100 young over a 20-day period. Aphids can rapidly achieve very large populations.

Damage

- Aphids pierce plant tissue with their mouthparts and suck out the sap, causing deformed leaves and flowers.
- Aphids moult through a number of different stages before they become adults. The cast-off skins they leave behind each time they moult are a visible sign of their presence.

- They excrete a sugary, sticky substance called honeydew, which promotes the development of black, sooty mould fungus.
- Some aphids can transmit plant virus diseases, such as cucumber mosaic virus in cucumber crops.

Control Strategies

- When monitoring for aphids, check for winged adults on yellow sticky boards.
- For wingless aphids, it is necessary to inspect new foliage carefully and regularly to prevent large infestations.
- Spot-treating isolated infestations can prevent their spread to the rest of the greenhouse.

Biological Control

- Several types of biological control agents are readily available: the predatory midge *Aphidoletes aphidimyza*, the parasitic wasp *Aphidius* spp., and ladybeetles or ladybugs (*Hippodamia convergens* and *Harmonia axyridis*).
- *Aphidoletes* and ladybeetles are usually used to supplement the activity of *Aphidius* and for reducing aphid populations in "hot spot" areas.

Aphidoletes aphidimyza — In the adult stage, *A. aphidimyza* resemble small mosquitoes or fungus gnats. Females lay up to 200 eggs in their lifetime. Eggs are laid close to aphid colonies, so the orange-coloured larvae have a readily available food source on hatching.

- Eggs usually hatch after 2–3 days. After 7–14 days in the larval stage, they drop to the floor to pupate. The pupal stage usually lasts about 2 weeks. Adult *A. aphidimyza* feed on honeydew, and larvae can kill 3–50 aphids per day. Under natural day lengths, *A. aphidimyza* enters diapause between September and March — they are not effective during this period.

Aphidius spp. — This parasitic wasp does not enter diapause and is usually more effective during winter, early spring, and fall. During summer, other parasitic wasp species can parasitize *Aphidius* reducing their impact on aphid populations. Optimum conditions for *Aphidius* are 18°C–25°C and 80% RH. *Aphidius* completes its development from egg to adult in about 10 days at 25°C and 14 days at 21°C.

- Several species of *Aphidius* are commercially available. *Aphidius matricariae* can parasitize about 40 aphid species, including the green peach aphid, while *Aphidius colemani* is more effective against the cotton aphid, but still works quite effectively against the green peach aphid. *Aphidius ervi* is the best choice against the potato aphid.

Hippodamia convergens — Both adult and larval ladybeetles feed on aphids. Larvae can feed on a total of about 400 aphids while adults feed on up to 5,000 aphids each. Ladybeetles enter diapause under short-day conditions. When day lengths are suitable, ladybeetles must feed on aphids to maintain egg production. Eggs are torpedo-shaped and orange-coloured. They are laid in circular clusters on the underside of leaves, and hatch in 2–5 days.

- The larval stage lasts for about 3 weeks, after which they pupate. Adults emerge from pupal cases after 3–5 days. To increase the percentage of ladybeetles remaining in the greenhouse, release them in late evening and

sprinkle a sweet liquid (e.g., diluted pop) over the beetles. The sweet liquid provides an immediate energy and water source.

Harmonia axyridis — This ladybeetle is also known as the multi-coloured Asian ladybeetle, Asian ladybeetle, Japanese ladybeetle or Halloween ladybeetle. Adults are oval, convex, about 6 mm long and occur in many colour forms. They are most commonly orange with black spots, or they may be black with red spots. Eggs are yellow and laid in clusters underneath leaves. The larvae are usually blackish with bright yellow spots along their sides. Total time for development from egg to adult at 25°C is 16–20 days. Females live 2–3 months and lay several hundred eggs each during their lifetime. Adults and larvae are voracious feeders and are reported to consume approximately 50–100 aphids per day.

Cabbage Loopers

Description and Life History

Cabbage loopers are pale green caterpillars with several wavy white lines along the length of the body. Loopers can be up to 4 cm in length and characteristically move by forming a loop with their bodies. Tiny loopers hatch from pinhead-sized pearly white, round eggs which are usually laid on the undersides of leaves. Loopers feed mainly on the undersides of leaves and excrete dark green frass (droppings) in the vicinity of the feeding area. This feeding or caterpillar larval stage lasts about 2 weeks, after which the mature larva pupates inside a webbed cocoon attached to the undersides of a leaf. The pupa is light green at first, becoming increasingly darker as it matures. Pupation can also take place under ground plastic, or in the ground along side-walls. The adult emerges in about 2 weeks and is greyish brown with a silvery spot resembling the figure eight on the middle of each front wing. The life cycle is completed in about 28 days.

Generally, cabbage loopers are not able to overwinter in Canada and infestations start each year with the arrival of adults from southern U.S. However, if conditions are favourable, loopers are able to survive in greenhouses from one season to the next [*Plate* 85].

Damage

Damage by young loopers consists of small areas on the undersides of leaves that have been superficially chewed and scraped away. As the loopers increase in size, they cut through the plant tissue leaving ragged holes between the leaf veins. The size of the holes is proportional to the maturity of the loopers. These caterpillars can also feed on fruits, but they are more often observed on the foliage. Most of the damage is carried out by the last two larval stages.

Control Strategies

Their initial presence can be detected through the use of light or pheromone traps. Light traps are useful during cooler months of the year when the risk of attracting additional moth pests is lessened. Pheromone traps can be used to detect the presence of male moths. Principal control strategies include the following:

- Proper sanitation between crops to remove any residual populations, thereby preventing early infestation of the new crop.
- Use of light traps to kill adults.
- Use of insect screens over vents and doorways to prevent entry of adults into the greenhouse.

- Frequent applications of the bacterial insecticide, *Bacillus thuringiensis* (Dipel, Foray), to target particularly the younger larval stages.
- Release of biological control agents such as the parasitic wasp, *Trichogramma* spp., that attack the egg stage of the cabbage looper, and another parasitic wasp, *Cotesia marginiventris*, that attacks the larval stage.

Lygus Bugs

Description and Life History

The lygus bug is also commonly known as the tarnished plant bug. The adult is 5–6 mm in length, flat, oval-shaped, greenish brown in colour, with a small Y-shaped yellow mark on its back. The younger stages or the nymphs are light green and resemble aphids except they move swiftly when disturbed. All stages (except eggs) of the lygus bug have stylets used to pierce young or succulent plant parts for extracting juices. They feed on a wide range of plant hosts including most vegetable and fruit crops and many weeds. Adults usually overwinter in protected areas in plant debris outdoors and emerge from these overwintering sites in early spring to seek out egg-laying sites, such as in greenhouse crops. When they find a suitable plant host (including greenhouse peppers and cucumbers), eggs are inserted into the plant tissue and nymphs hatch out after a few days. They undergo 5 nymphal stages completing their life cycle in about 4 weeks, depending on temperature. There are about 3 generations outdoors in southwestern Ontario, and perhaps a few more in greenhouses [*Plate* 86].

Damage

Lygus bugs feed on flowers and shoot tips. They cause damage by piercing the tissue and injecting saliva that causes death or distortion of the tissue. Such feeding results in loss of growing points, flower abortion, distortion of new growth as in developing leaves, flowers, and fruits. Loss of growing points characteristically results in development of bushy plants, e.g. in peppers, because of the simultaneous growth of side shoots. Yellow varieties of pepper appear to be particularly attractive to this bug.

Control Strategies

Monitoring for lygus bugs is best done using a combination of yellow sticky cards and crop inspection. Often they may be observed on the cards before they are detected in the crop. The first line of defence is to control weeds in the immediate greenhouse area, starting the previous fall. This discourages nearby overwintering populations that serve as a source of infestation the following spring. Maintain a well-mowed surrounding area. Use coarse insect screens to prevent entry of adult bugs.

Biological Control

Good populations of generalist predators such as *Orius* have been associated with suppression of lygus bugs. A parasitic wasp, *Anaphes iole*, attacks only the egg stage and is available for biological control. There are other biological control agents still on trial. These may be available in future for an expanded biological control program for lygus bugs.

European Corn Borer

Description and Life History

The larva is the damaging stage of the European corn borer (ECB). It is grey to tan in colour with dark spots along the back, and with a brownish-black head. These caterpillars spend most of their life feeding within its host e.g. pepper fruits. Outdoors, it is the final and fifth larval stage that overwinters in corn debris in the fall and completes development to the adult stage the following spring. Adults, which are about 1.5–2.0 cm long, light brown with dark wavy bands, search for suitable hosts such as corn and peppers, and lay eggs on the undersides of leaves in a mass of 5–50 eggs that appear as fine fish scales. Egg-laying is favoured by warm, calm evenings and overnight dew. Immediately after hatching, the tiny larvae feed very little or immediately spin a web from which it hangs until it finds a pepper fruit. At that point, the larva bores its way, usually under the calyx, into the fruit and settles down to eating and growing by moulting 5 times. The final larval stage can either pupate within the fruit or bore its way out of the pepper and pupate outside of the fruit. European corn borers normally begin infestations in spring around May to early June. There are two generations of this borer in southwestern Ontario, and one generation elsewhere in Ontario [*Plate* 87].

Damage

Of the major greenhouse crops (tomato, cucumber, pepper, lettuce), only pepper is attacked by ECB. Fruits are the target for feeding, whereas damage to leaves is non-existent or insignificant. The larva bores into the fruit and feeds on the internal portion of the fruit. In addition to the direct feeding damage, the entry holes facilitate eventual rotting and breakdown of the internal tissues of the fruit. Early infestation of pepper fruits may be difficult to detect because the caterpillar inconspicuously bores into the fruit under the calyx. However, their presence is indicated by premature colouring of the fruit, and by the presence of light brown droppings around the entrance hole. For more information on European corn borer, see OMAF Factsheet *European Corn Borer in Field Corn*, Order No. 97-021.

Control Strategies

Monitoring and Cultural Control

To monitor for ECB in spring, use pheromone and black light traps to detect initial flight of the adults. Light traps attract both males and females; pheromone traps attract only males. However, management of ECB begins with clearing of overwintering sites such as corn fields and grassy areas during the previous fall.

Physical Control

Entry by adults into the greenhouse may be reduced by using coarse screens over vents, doorways and all openings. To attract adults away from the greenhouse, place ultra violet light traps that attract and kill adult ECB, outside the greenhouse at least 10–20 m away. Such traps require a timed power source and regular cleaning of the electrocution mechanism.

Biological Control

The parasitic wasp, *Trichogramma brassicae*, has been used with some success in field corn trials. It is a tiny wasp that attacks only the egg stage and requires even distribution throughout the crop for maximum effectiveness. Its effectiveness in greenhouse peppers still has to be determined.

Fungus Gnats/Shore Flies

Description and Life History

The grey to black adult fungus gnat is about 3–4 mm long with long legs, thread-like antennae and large compound eyes that meet above the base of the antennae. The adult is a weak flier, frequently observed resting on the media surface. Each female lives about 10 days and lays about 150 oval, white eggs in the organic matter of the media. Eggs hatch in 2–7 days, depending on the temperature, producing white larvae that are 4–6 mm long [*Plate* 88].

The larvae have 12 abdominal segments and a distinctive shiny black head. The larvae spin pupal cases and remain immobile in the soil for 4–6 days, after which adult flies emerge. As with most insects, fungus gnats become more active and reproduce more quickly at warmer temperatures. The life cycle can be completed in 21 days at 24°C, compared with 38 days at 16°C.

Shoreflies, another common greenhouse pest, are often confused with fungus gnats. The adults are stouter than fungus gnats, stronger fliers and have 5 clear spots on the wings. The larvae live in the growing media, like fungus gnats, but lack the distinctive black head capsule. They are likely to prefer moister conditions than fungus gnats and are often found in wet areas under benches with both adults and larvae feeding on algae.

Shoreflies are not usually a threat to greenhouse crops, but can feed on roots, presenting a potential threat for disease infestations. Shorefly control requires controlling algae, either directly (by applying chemicals) or indirectly (by reducing moisture necessary for algal growth; or reducing the high light levels the algae need).

Damage

- Although fungus gnats generally feed on decaying organic matter in the soil, they can also feed on the young roots of plants. This is especially true when gnat populations are high.
- They have occasionally been observed feeding on the youngest shoots of cucumbers.
- Root feeding by fungus gnats makes a plant susceptible to root diseases such as *Pythium* root rot. Fungus gnats have also been implicated in the spread of disease-causing organisms such as *Pythium*, *Fusarium*, *Verticillium* and *Rhizoctonia*.

Control Strategies

- Sanitation inside the greenhouse and in the surrounding outside area is very important.
- Avoid overwatering and maintain good drainage to prevent water puddling — fungus gnats and shoreflies thrive in moist conditions.

Biological Control

Biological control agents include predatory mites, *Hypoaspis* spp., and a parasitic nematode, *Steinernema feltiae*.

Hypoaspis — *Hypoaspis* is a soil-dwelling, brown mite that feeds on fungus gnat eggs and larvae, algae, thrips pupae, springtails, nematodes, and larvae of various flies and beetles. *Hypoaspis* is a hardy mite that can live about 24 days without food. It is not affected by low light conditions and has a life cycle of about 9–11 days under greenhouse conditions.

Hypoaspis is found mainly in the top 1 cm of the growing media. It works best when applied to the media just after plants are potted up or vegetable seedlings planted out. *Hypoaspis* is most effective when fungus gnat populations are still low or non-existent.

Atheta coriaria (rove beetle) — *Atheta coriaria* is a small, black soil-dwelling beetle [*Plate* 89] about 3–4 mm long. It is very active and both the adult and the 3 larval stages feed on fungus gnats (eggs and larvae) and thrips (pupae). It is produced and sold commercially, but is also naturally occurring and often found in greenhouses where pesticide use is reduced. It should be used in a similar fashion to *Hypoaspis*, introduced into the crop early to control soil-dwelling pests.

Nematodes — The nematode, *Steinernema feltiae*, is best used under higher population conditions. Nematodes enter the body openings of fungus gnat larvae, then release bacteria, which multiply and kill the larvae. Because nematodes may not adequately multiply within the bodies of fungus gnat larvae, use several consecutive nematode applications to achieve control. *To use nematodes successfully:*

- Shake nematode stock solutions every hour to incorporate oxygen into the water.
- Use the solution within 4 hr.
- Media temperatures should be 16°C–30°C.
- Never expose nematode suspensions to direct sunlight. This will destroy the bacteria within the bodies of the nematodes.
- Do not expose nematodes to a pH that is <3 or >8.
- Check the compatibility or residual activity of fungicides before applying to media that have been, or will be, treated with nematodes.

Tomato Pinworm

Description and Life History

The tomato pinworm (TPW) is a semi-tropical pest that can infest tomato crops in Ontario. Other suitable hosts for TPW are potatoes and eggplant. Weeds such as nightshade and its relatives may also serve as hosts. The adult is a small, light-brown moth about 6 mm long. It is generally more active at night, laying most of its eggs on younger leaves during the first few nights of activity. Newly hatched larvae walk on the leaf surface for a very short time before entering the leaf to start mining [*Plates* 90, 91, 92]. There are 4 larval stages, the first two of which are spent in the leaf. The 3rd and 4th stages may be found between 2 leaves knitted together, in a leaf that has been folded over, or inside fruits. Larvae characteristically enter fruits just beneath the calyx. Mature larvae may either remain on the plant or drop to the ground to pupate. On the ground, pupation usually occurs within the top 15 cm of soil. Tomato pinworms do not diapause. Their development continues year round, slowing during cold weather periods. Development time from egg to adult usually ranges between 19–70 days, depending on temperature. The life cycle is completed in 28 days at 24°C, and can be as short as 19 days at 30°C.

Damage

It inflicts damage by feeding on tomato leaves and fruit. Tunnelling or mining by larvae in the leaves is the most common type of injury. Initially, the mine is long and narrow,

but it later widens to become blotch-shaped. Older larvae may fold the leaf over itself, or knit two leaves together, between which they continue to feed, causing large blotches. In severe infestations, all leaves on a plant are attacked giving the crop a burnt appearance. More direct damage is caused to the crop when the older larvae penetrate nearby fruits by burrowing under the calyx into the fruit. Very small pinholes are left at the points of entry which are often marked by the presence of a small amount frass or droppings. Points of entry under the calyx are inconspicuous and can easily be overlooked during packing. Larvae may also bore into the sides of tomato fruits in heavily-infested crops.

Control strategies

- Inspect all seedlings for larval feeding damage.
- Destroy all old infested plants and any debris from infested crops.
- Monitor for their presence with pheromone or light traps, and by inspecting crops regularly. Note that pheromone traps attract only male TPW, whereas light traps attract both sexes of TPW and many other insect species.
- Hand-pick damaged leaves and destroy larvae within the mines.
- Destroy weeds and stray tomato seedlings inside and around the greenhouse.
- Install insect barriers over vents.

For more information on this pest, see OMAF Factsheet, *Tomato Pinworm – Its Biology and Control Strategies for Greenhouse Tomato Crops*, Order No. 98-009.

Potato Psyllids

Description and Life History

Potato psyllids have 3 life stages: eggs, nymphs and adults.

- **Eggs.** The eggs are very small, football-shaped, yellow to orange in colour and borne singly on very fine stalks, usually along leaf margins. A 10× hand-lens is necessary to see the eggs.
- **Nymphs** are flattened and somewhat scale-like with a fringe of short spines around the edge. Younger nymphs are pale brown, turning green with each successive molt. Nymphs are usually found on lower leaves and on lower leaf surfaces. When disturbed, they move quite readily. They secrete a white substance that looks like granulated sugar or salt, and collects on leaves beneath the feeding nymphs [*Plate* 93].
- **Adults**, sometimes referred to as "jumping plant lice," look like small cicadas and are about 2 mm long, greenish to black, with a distinctive white "band" around the abdomen. They have clear wings that are held roof-like over the body. As the name suggests, they jump and fly readily when disturbed. Recently emerged adults are pale yellow to light green, and later turn gray or black.

A mature female can lay over 500 eggs during an average egg-laying period of 21 days. The average time required for development from egg to adult is 15–30 days, and a temperature of 27°C favours their development and survival. Temperatures below 15°C or above 32°C adversely affect their development and survival.

Damage

Potato psyllids, like aphids and leafhoppers, suck plant sap through needlelike mouthparts. They feed in a similar manner to aphids, but instead of producing a shiny film of honeydew on the leaves, their sugary exudate resembles a white powder. The nymphs are the damaging stage because when feeding, they inject a toxin that causes a physiological condition known as "psyllid yellows". Feeding by this pest not only causes yellowing of the plant, but can also result in loss of vigour and yield due to a combination of reduced fruit set and fruit size. Damage symptoms include stunting, chlorosis and purpling of leaves, distorted leaf growth, and small, poor quality fruit. Infestations of pepper crops by psyllids are reported to be less damaging because no yellowing occurs. However, the powdery deposits on the fruit have to be washed off before they can be marketed.

Control Strategies

Monitoring

Carry out weekly inspection of plants to check for the powdery exudate and nymphs that can occur either on the upper or lower leaf surfaces. Yellow sticky cards hung close to the top of the plant canopy will also catch the winged black adults which, to the naked eye, resemble winged aphids.

Physical Control

This entails removal of infested leaves and provides a rapid means for reducing the population.

Biological Control

There is indication that the predatory bugs, *Dicyphus hesperus* and *Orius insidiosus*, and the parasitic wasp, *Tamarixia triozae*, may contribute to suppression of psyllids. However, use of *Orius* may not be as useful on tomatoes because young *Orius* nymphs tend to get caught on the sticky hairs present on tomato plant surfaces.

Chemical Control

There are no pesticides in Ontario that are specifically recommended for psyllids.

Leafminers

Description and Life History

Two main species of leafminers are important to Ontario growers: the vegetable leafminer *(Liriomyza sativae)* and the serpentine leafminer *(Liriomyza trifolii)*. A third species, the pea leafminer, *Liriomyza huidobrensis*, which is a major pest in other parts of the world, has also been found in Ontario. Although the serpentine leafminer can complete development on tomatoes and cucumbers, it prefers chrysanthemums, gerbera and gypsophila. Conversely, the vegetable leafminer prefers tomatoes, cucumbers and celery, but will attack chrysanthemums and other plants in the absence of its preferred host. The pea leafminer has a wider host range and can move into field grown crops as well, including vegetable crops such as cole crops, lettuce and celery. The three species of leafminers are similar in appearance and biology.

The adult leafminer is small (approximately 3 mm long), with black and yellow markings on the head and thorax. Adults become active at sunrise. Females feed on soft, succulent leaves by piercing the surface with their ovipositor, then lapping the liquid exuding from the wound.

Female flies begin laying eggs 12–24 hr after emerging from the pupa. They lay about 250 eggs during their approximately 30-day lifetime. Eggs are laid in about 1 out of 7 leaf punctures (or "stipples"). The optimal temperature for leafminer development is

30°C. At temperatures above or below 30°C, egg production/female declines considerably. After 2–4 days, eggs hatch and the larvae begin feeding (or mining) in the leaf tissue [*Plate* 94].

The larvae mature in 4–7 days in summer, then cut a hole in the leaf surface and drop to the ground. Pupation takes place within a few hours, in the plant media or on plastic sheeting (where used). Pupation can also occur on the leaves. The pupal stage may last 5–10 days in the summer and up to 90 days during periods of low temperature (10°C–12°C) and scarce food supply. This may account for the winter survival of leafminers around the inside perimeter of the greenhouse, though no adult leafminers are evident. From the pupae, a new generation of adult flies emerges.

There is considerable overlapping of stages of the insect life cycle within any greenhouse. The complete life cycle of the leafminer can be as short as 14 days at 30°C, 24 days at 20°C and 65 days at 14°C.

Damage

Leafminer feeding may indirectly affect yield by reducing the plant's photosynthetic area, and by damaging water-conducting vessels (causing leaf desiccation and leaf drop).

Control Strategies

- Inspect all new plant material entering the greenhouse.
- Destroy infested seedlings, cuttings and plant parts.
- Monitor the crop for pests with yellow sticky boards and regular crop inspections.
- Get rid of weeds inside and outside the greenhouse. Weeds such as lamb's-quarter, chickweed, dandelion, plantain, common mallow and nightshade are good hosts for leafminers.
- Do not over fertilize the crop — excess nitrogen levels can increase aphid and leafminer problems.
- Detached leaves should be bagged and removed from the greenhouse as soon as possible. Leafminer larvae can complete their development in leaves even after they are removed from the plant.

Biological Control

Biological control agents include the parasitic wasps, *Diglyphus isaea* and *Dacnusa sibirica*. *Diglyphus* is likely to be a better choice in summer, when its numbers may be supplemented by naturally occurring populations migrating into the greenhouse from outside. *Dacnusa* will perform better than *Diglyphus* over the winter.

Diglyphus isaea — *Diglyphus* is a small, black wasp with a metallic, green sheen and short antennae. After locating a mine, the female first paralyzes the leafminer, then inserts an egg through the leaf, placing it near the leafminer. It may deposit up to 5 eggs this way, laying about 60 eggs during its lifetime. The larva that hatches is initially colourless, then becomes yellow-brown and finally turquoise. Development time from egg to adult is about 11 days at 25°C. This is generally shorter than that of both the leafminer and *Dacnusa*.

Diglyphus can parasitize leafminers already parasitized by *Dacnusa*. It becomes the dominant species during summer, when warm conditions favour their activity. Presence of short mines indicates *Diglyphus* activity, as the paralyzed leafminer stops feeding immediately.

Dacnusa sibirica — The adult is a small, black wasp that differs from *Diglyphus* in having long, flexible antennae and in lacking the metallic, green sheen. Unlike *Diglyphus*, a female *Dacnusa* inserts an egg into the body of the leafminer. Each female lives for about 2 weeks, during which time she may lay up to 90 eggs.

Eggs hatch within 4 days, and the larvae mature within the leafminer pupae. Development time from egg to adult is about 2 weeks at 22°C. All *Dacnusa* development takes place within the leafminer's body; therefore, assessing parasitism is difficult.

Occasional Greenhouse Pests

Ants

Ants are easily recognized by their elbowed antennae and narrow waists. They range from 1.5–6 mm long.

Ants are attracted to sweet substances. In greenhouses where insect feeding has produced honeydew, or where flowers have nectaries, ants may be a problem. Treat all ant trails or nests located in or near the greenhouse. Flooding nests with insecticidal soap and using household boric acid baits can provide some control.

Caterpillars

Several different insects have caterpillar stages that damage greenhouse crops. These include leaf rollers, armyworms, cutworms, loopers, fruitworms, hornworms and leaf tier and stalk borers. The adult moths of these caterpillars are often attracted to greenhouse lights in the summer, and will then lay eggs that hatch into the caterpillar pest.

- Armyworms and cutworms feed directly on plant foliage and may cause considerable damage. Both insects are dark brown or grey with longitudinal stripes. Cutworms burrow into the soil during the day and come out to feed at night.
- Use insecticides recommended for caterpillars to bring armyworm and cutworm infestations under control.
- Stalk borers bore into plant stems, making them more difficult to control.
- Pheromone traps can be used to detect certain moth species and light traps can be used to monitor many species.
- If these pests are detected early, apply controls immediately afterwards. Screened vents help prevent the entry of all adult stages of the caterpillars, and a good inside/outside weed control program will reduce potential infestation sites. Apply the bacterial insecticide, Dipel or Foray, for good control of loopers and most leaf-eating caterpillars that are not miners.

Grasshoppers

Grasshoppers are easily recognizable and occasionally invade greenhouses.

- They will feed on almost any vegetation and, in large numbers, can destroy plants.
- Grass and weeds near greenhouses may allow a grasshopper infestation to occur, usually in late summer and fall.

Slugs and Snails

Slugs are dark grey, soft-bodied creatures, 1.3–10 cm long. They glide over plants leaving a shiny trail. Slugs eat the foliage of most greenhouse plants, shredding the leaves, and they may completely destroy a plant.

Snails are similar in colour and appearance to slugs, except that a snail bears a noticeable shell. The shell varies in colour and markings, and may be 1.3–5 cm in diameter. Snails are particularly injurious to seedlings.

- They eat holes in the flowers and leaves of many plants.
- Individual snails may lay up to 100 eggs, depending on the species. Slugs lay fewer eggs that may remain unhatched for long periods under dry conditions. They hatch upon return of moist conditions.
- Both slugs and snails need a damp environment and fairly humid air to survive. They avoid the sun and come out primarily at night or on cloudy days. During the day, slugs hide under boards and rocks or in other damp, shady places. If the air or substrate is dry, a snail can pull its entire body into its shell and remain dormant for up to 4 years.
- Some growers have reported good control of slugs by using certain parasitic nematodes.
- Indirect control strategies for these organisms should focus on reducing their favoured habitat. These strategies include:
  - remove boards, bricks, etc. that are in contact with the ground, or arrange these to permit proper air circulation around and under them
  - maintain a plant density that permits sunshine to penetrate to the ground level, provides good air circulation and allows the plant media to dry
  - where a low plant density is inappropriate, use a ground cover unattractive to snails (e.g., rough cut cedar chips or crushed eggshells)
  - sawdust and diatomaceous earth are an effective barrier if kept dry.
- Various devices can trap or attract slugs and snails for subsequent destruction.
  - Traps can be made using beer or a mixture of water and commercial yeast as an attractant.
  - Inverted flower pots with crushed snails or slugs, or inverted grapefruit halves, are good devices for attracting slugs and snails.
- Chemical controls involve baited pesticides that combine bran bait with metaldehyde.
  - Metaldehyde is toxic. Do not expose to children and pets.
  - Prolonged use of baits is likely to produce a local bait-resistant population.

Sowbugs/Pillbugs

Sowbugs and pillbugs have grey, flattened, oval bodies up to 13 mm long with 7 pairs of legs. Sowbugs have 2 small, tail-like structures that the pillbugs lack.

- They are both small decomposers, but occasionally feed on roots and tender plant parts causing seedling damage. They feed at night and hide during the day, preferring dark, moist areas with abundant organic matter.

- Sterilizing soil and eliminating decaying plant material and moist areas will help prevent a build-up of these pests.
- Many strategies used for snail and slug control also suppress sowbug/pillbug populations.

Springtails

Springtails are tiny, wingless insects 2–6 mm long. They range in colour from white, grey or yellow, to red, orange, purple, brown or mottled hues.

- They are usually found on the surface of moist soil, in pots or within the soil.
- They have a spring-like apparatus at the end of the abdomen that allows them to spring into the air.
- Most springtails are scavengers, feeding on decaying organic matter, algae or fungi. Because they usually do not feed on living plant material, chemical controls are rarely necessary.

Striped Cucumber Beetles

Striped cucumber beetles are yellow-green beetles about 6 mm long. They have 3 longitudinal stripes. These beetles and a relative, the spotted cucumber beetle, carry the bacteria, *Erwinia tracheiphila*, which causes bacterial wilt in cucumbers and related species such as melons and squash.

- Striped adult cucumber beetles overwinter outdoors under old leaves, old logs or trash. They emerge the following spring, mate and feed for several weeks, then lay orange-yellow eggs in the soil at the base of plants.
- Larvae usually hatch in 10 days, then feed on the roots of plants for 2–6 weeks. Fully-grown larvae are about 9 mm long. Pupation takes place in the soil and adults emerge after about 1 week. There is only 1 generation per year in Ontario.
- The adult beetles damage plants by chewing on leaves, stems and fruits, but the greatest damage comes from the wilt-causing bacteria they often carry in their gut. The bacteria survive the winter in the gut of the overwintering beetles. In the spring, the beetles inoculate plants with the disease as they feed on the plant tissue.
- There is no control for the wilt once a plant is infected. Inoculated leaves generally wilt within 5–6 days and the plant dies within 2 weeks. Striped cucumber beetles can also transmit cucumber mosaic virus.
- Best control comes from insect barriers installed over all greenhouse openings to exclude the adult beetles.

Symphylans

Symphylans are found under stones, in rotting wood, and in moist soil high in decaying organic matter. They are small white creatures resembling centipedes, with slender, long, white bodies (1–5 mm long), 10–12 pairs of legs and long antennae. (Centipedes have 15 pairs of legs.)

- While centipedes are beneficial predators that prey on many insects, symphylans can feed on the roots of plants. On many crops, damage shows as tiny black marks on the roots where a hemispherical piece of tissue has been scooped out. Injured roots become stubby and the plant becomes stunted.
- Damage caused by symphylans to roots and root hairs provides entry points for root-rotting diseases.

Vertebrate Pests

Rats and mice may be very destructive in the greenhouse. They feed on almost any food source and can cause damage by gnawing and burrowing.

- Norway rats and field mice are the most common vertebrate inhabitants of greenhouses. Baits containing rodenticides such as chlorophacinone, diphacinone, warfarin and zinc phosphide can give some control. The first 3 chemicals are anticoagulants and multiple doses are usually required. Zinc phosphide is not an anticoagulant and is more acutely toxic—a single dose can achieve kill.
- Ensure that the toxic baits are placed in covered stations where pets cannot get them.
- To minimize the development of rodenticide resistance, particularly to the anticoagulants, always adopt other control measures:
  - store all potential food material in tight-fitting containers
  - use many traps where there are signs of activity, placing one trap every 2–3 m along walls
  - set traps at right angles to the wall, with the bait and trigger facing the wall
  - handle traps with gloves to avoid contaminating them with human smells
  - try different baits. Suggested baits include peanut butter mixed with oats, raisins, gumdrops or any other sticky food material, and cotton (which provides nesting material)
  - maintain several female cats as biological control agents. Female cats tend to be more predacious than males.

Root Nematodes

These are not a major problem in hydroponic vegetable production but are seen occasionally where poor greenhouse hygiene exists.

Plant parasitic nematodes are small (<1 mm long) worm-like organisms that live in the root media. They are broadly divided into 2 groups — ectoparasites (which attack plants externally) and endoparasites (which spend at least part of their life cycle within the plant tissue).

- All parasitic nematodes have stylets through which they inject saliva into the plant tissue. The saliva causes most of the damage. It results in necrosis or the proliferation of giant cells that produce galls.
- Nematodes cause damage mainly by reducing the ability of plants to absorb water and nutrients. Above ground symptoms of nematode damage include weakened plants that wilt in the sun, yellow or pale green leaves and stunted fruit or flowers.
- Where nematocides are used between crops, nematode infestations often recur because of insufficient penetration of the chemicals into the lower soil levels. Soils so treated should always be properly aerated to avoid subsequent plant damage.

Root-Lesion Nematode, Pratylenchus penetrans (Cobb) — This endoparasitic nematode is native to Ontario soils and can attack many floral and vegetable crops.

- All stages are thread-like and invisible to the naked eye.
- This nematode invades the outer layers of young roots, causing small brown-to-black elliptical lesions that merge to discolour the roots and kill them.

Northern Root-Knot Nematode, Meloidogyne hapla (Chitwood) — This is another endoparasitic nematode native to Ontario soils. It attacks almost all types of vegetable crops and many floral crops, particularly roses, African violets and geraniums.

- Early larval stages are thread-like and invisible, while later stages and adults are peanut-to-pearl shaped and just visible when dissected from roots.
- This nematode invades roots and settles down to cause swellings, knots, or galls, and excessive root proliferation. Infested roots do not necessarily become discoloured unless attacked by bacteria and fungi.

Dagger Nematode, Xiphinema diversicaudatum (Micoletzky) — This ectoparasitic nematode is not native to Ontario and was introduced into greenhouses on plant stocks. Dagger nematodes prefer plants with woody roots, and are more frequently associated with crops such as strawberry, grapes, and roses.

- The nematode survives in the root crotches of the understock.
- One of the largest nematodes attacking plants, this 6 mm long, thread-like roundworm can, with care, be seen on the roots. It feeds on young roots from the soil, causing galls similar to root-knot galls but somewhat larger. These galls are actually curved swellings in the root tip area, accentuated with the necrosis and shriveling of roots above the galls.

Pin Nematode, Paratylenchus projectus (Jenkins) — This nematode is native to Ontario and can attack many floral and vegetable greenhouse crops. All stages of pin nematode are thread-like and invisible to the naked eye.

- This species is active in both fine textured (clay) and coarse textured (sandy) soils.
- The pin nematode does not enter roots, but feeds at root tips by probing root hairs and surface cells. No specific root symptoms (such as galls or lesions) appear. Plants infested with this nematode show general above ground symptoms.

Southern Root-Knot Nematode, Meloidogyne incognita (Kofoid and White) — This endoparasitic nematode is not native to Ontario, but has become persistent in the protected greenhouse environment. It cannot survive outdoors during winter. It is a bad problem on tomato and cucumber, but can also attack several floral and foliage crops.

- Root damage and symptoms differ from those of the northern root-knot nematode. Plants damaged by the southern root-knot nematode have larger galls and lack fine root growths from the galls.
- Tomato leaves may show phosphorus deficiency (purpling) on the underside, or downward curling of leaf edges; affected tomato or cucumber plants wilt readily.

Foliar Nematodes — A few nematodes attack plant foliage. Symptoms caused by leaf-feeding nematodes are similar to those of several diseases and nutrient deficiencies.

14. Pesticide Toxicity and Activity

The LD_{50} of a pesticide listed in Table 14–1, *Insecticide and Miticide Toxicity and Classification* and Table 14–2, *Fungicide Toxicity and Classification* is a measure of its relative toxicity. This is the amount of the active ingredient (a.i.) of the chemical in milligrams used per kilogram of test animal (usually female rats) that kills 50% of the test animals. This is commonly measured as the acute oral LD_{50}, which refers to the chemical ingested through the mouth or nose. Dermal LD_{50} figures, or skin penetration, are also available. The higher the LD_{50} figure, the less toxic the product is to humans.

Note: Many pesticides of low acute toxicity cause long-term effects in laboratory animals. Users are therefore warned that these could be detrimental to human health. Reduce exposure to a minimum by wearing protective clothing, including latex gloves, goggles and long-sleeved shirts.

The Ontario Schedule Number referred to in Tables 14–1 and 14–2 is a classification under Ontario's Pesticide Act, which is administered by the Ministry of Environment. The act prohibits the sale and use of a pesticide product unless it is registered under the federal Pest Control Products Act and classified into one of six schedules. See Chapter 1, *Precautions with Pesticides*, for more information on this classification system.

Inclusion of a product in these tables does not necessarily imply registration for greenhouse use or registration for a specific crop. **Read every product label to ensure suitability for a particular crop!**

TABLE 14–1. Insecticide and Miticide Toxicity and Classification

Common Name	Trade Name	Oral LD_{50} (mg a.i./kg)	Chemical Family	Ontario Schedule Number
Abamectin	Avid	300	Avermectin	3
Bacillus thuringiensis	Dipel, Thuricide, Vectobac, BioProtec, Foray	15,000+	Biological	3
Diazinon	Diazinon, Basudin	300	Organophosphate	2
Endosulfan	Thiodan, Thionex	110	Organochlorine	2
Fenbutatin oxide	Vendex	2,631	Organotin	3
Imidacloprid	Intercept	1,858	Chloronicotinyl	5
Malathion	Malathion	1,400	Organophosphate	3
Naled	Dibrom	430	Organophosphate	2
Nicotine	Nicotine Smoke	50	Botanical	2
Permethrin	Ambush, Pounce	4,000+	Synthetic Pyrethroid	3
Pyridaben	Dyno-Mite	1,930	Pyridazinone	3
Tebufenozide	Confirm	>5,000	Insect Growth Regulator	2
Tridecenyl acetate	3M Sprayable Pheromone for Mating Disruption of Tomato Pinworm	>5,000	Pheromone	2

TABLE 14–2. Fungicide Toxicity and Classification

Common Name	Trade Name	Oral LD_{50} (mg a.i./kg)	Chemical Family	Ontario Schedule Number
Captan	Supra Captan, Maestro	9,000	Phthalimide	2
Copper	Fixed Copper	5,000+	Copper	3
Dicloran	Botran	10,000+	Dicarboximide	3
Fenhexamid	Decree	5,000+	Anilide	2
Iprodione	Rovral 50WP	3,500	Dicarboximide	3
Mancozeb	Manzate	>5,000	Dithiocarbamate	3
Metalaxyl-M	Ridomil Gold	667	Phenylamide	2
Myclobutanil	Nova	1,870	Triazole	2
Oxine benzoate	No-Damp	1,000+	Aromatic hydrocarbon	3
Propamocarb hydrochloride	Previcur	>2000	Carbamate	2
Sulphur	Microscopic Sulphur	>5,000	Sulphur	3
Streptomyces griseoviridis	Mycostop		Biological	3
Trichoderma harzianum	RootShield		Biological	3

Pesticide Injury to Vegetable Crops

Although greenhouse pesticides have been selected and formulated to avoid plant injury, damage can still occur under some conditions. Consider these general rules before applying pesticides.

- No product is safe on all plants under all conditions, although wettable powders are generally less injurious than liquid formulations.
- A material (e.g., smokes) may be safe when applied to dry foliage but can cause injury when used on wet foliage.
- Weather conditions at the time of application are important. Pesticides are more likely to be phytotoxic when applied during bright sunny weather than if applied during dull, overcast conditions.
- Well-watered, unstressed plants are less likely to be damaged by pesticides.
- Low-volume applications are generally less likely to cause plant injury than high-volume applications.

15. Pesticides Registered for Greenhouse Vegetables

TABLE 15–1. Tomato Pests

Pesticide	Rate	Pest	Pre-harvest Interval (days)	Remarks
Ambush 50 EC or Pounce EC	200 mL/1,000 L 260 mL/1,000 L	whiteflies	1	Apply to achieve thorough coverage. Repeat as necessary.
Avid	30 mL/100 L	two-spotted spider mite leafminer	3	No more than 5 applications/crop cycle. Apply 600–1,200 mL Avid/ha. Use in sufficient water to obtain coverage. (2,000– 4,000 L water/ha).
Bioprotec	1.8 L/1,000 L water. 0.9–1.8 L/1,000 L water.	cabbage loopers tomato hornworm	0	Use diluted spray within 12 hr. Use product within 6 months of manufacture date. Addition of a wetting agent is recommended to improve distribution on foliage.
Confirm 240F	0.6 L/ha	cabbage loopers	2	Re-entry period is 12 hr. Application interval at least 10 days. Foliar application only. Do not exceed 4 applications/crop cycle.
DDVP 20%EC	6 mL/L	aphids, whiteflies	7	Use cautiously as crop damage can occur, particularly under hot, humid conditions. Thoroughly ventilate before re-entering on the day following treatment.
Dibrom	10 mL/100 m^3 Apply undiluted to cold pipes, then heat to 41°C and close greenhouse for at least 4 hr.	aphids, two-spotted spider mites, whiteflies	1	May cause injury to flowers. Ventilate greenhouse properly before re-entering.
Dipel 2X DF	75–150 g/250 L/ 4,000 m^2	cabbage loopers		Apply to upper and lower leaf surfaces to runoff. Repeat applications needed with new generations.
Dyno-Mite	284 g/ha using 1,000 L water/ha	two-spotted spider mites	2	Maximum number of applications/crop cycle is 2. Apply at intervals of at least 28 days.
Endeavor 50WG	100–200 g product/ha using a minimum of 1,000 L water/ha	aphids – green peach and melon aphids	3	Do not exceed 2 applications/crop cycle/year. Do not re-apply for at least 7 days. Use a surfactant for improved coverage.
Foray 48BA	0.6–1.8 L/ha (60–180 mL/1,000 m^2)	cabbage loopers	0	Apply using a high volume spray. Apply at 10 day intervals when loopers first appear. Use 500–1,000 L/ha.
Intercept	16 g/60 L water/1,000 mature plants	whiteflies, aphids	1	Do not apply more than once per season. Repellency of bumble bees and negative effects on some beneficials can occur.

TABLE 15–1. Tomato Pests (Continued)

Pesticide	Rate	Pest	Pre-harvest Interval (days)	Remarks
Insecticidal Soap	1–2 L/100 L	aphids, two-spotted spider mites, whiteflies, earwigs, psyllids		May cause damage to flowers under high temperature conditions.
Nicotine Smoke	1 can/300 m^3	aphids, thrips	3	Ventilate greenhouse properly before re-entering.
Sluggo	25–50 kg/ha (2.5–5 g/m^2)	slugs and snails		Re-apply bait as needed or at least every 2 weeks if slugs and snails continue to be a problem.
Thiodan/Thionex 4 EC	1.25–1.5 L/1,000 L/ha	aphids, whiteflies	2	Harmful to bees.
Thiodan/Thionex 50 WP	1–1.5 kg/ha			
3M Sprayable Pheromone for Mating Disruption of Tomato Pinworm	200 ml in 300–450 L water/ha (high volume) or 10 L water/ha (low volume foggers)	tomato pinworm	12 hr	Repeat applications are dependent on pressure and should generally be done 3–4 weeks apart.
VectoBac 600 L	2–8 L/1,000 L	fungus gnats	0	Do not mix and apply with fertilizers or fungicides containing copper or chlorine as this may neutralize the active ingredients.
Vendex 50W	50 g/100 L	two-spotted spider mites	5	Addition of a suitable spreader-sticker will improve mite control.

TABLE 15–2. Tomato Diseases

Pesticide	Rate	Disease	Pre-harvest Interval (days)	Remarks
Botran 75W	1.75 kg/1,000 L	Botrytis grey mould	1	Seedlings may be injured by drenching.
Decree 50 WDG	1.5 kg/ha	Botrytis grey mould	1	Do not make more than 3 applications per crop cycle.
Copper Spray Fixed Copper Fungicide	3 kg/1,000L/ha	bacterial canker		7–10 day interval.
Maestro 80DF	1.25 kg/1,000 L. Apply 50–85 L/100 m^2.	damping-off in seedlings		Work into the upper 7.5–10 cm of soil before planting.
Manzate DF	2.4 kg/ha	early and late blight, Septoria leaf spot	7	
Mycostop	As seed treatment — 5–8 g/kg seed	Fusarium damping off	0	
	Immediately after transplanting, apply 5–10 mg/plant or 10–20 mL/plant of 0.05% suspension	damping-off, root & crown rot, wilt caused by *Fusarium*; root and stem rot, and wilt caused by *Phytophthora*		Repeat treatments at intervals of 3–6 weeks depending on disease pressure.
No-Damp	10 mL/1 L	damping-off diseases in seedlings		
Nova 40W	340 g/ha (1,000 L water/ha)	powdery mildew	3	Apply no more than 2 applications/yr.
Rootshield Drench	60–90 g/100 L	*Pythium*, *Rhizoctonia*, *Fusarium*		Effective when root zone temperature more than 10°C and pH is neutral or acidic.
Rootshield Granules	600 g/m^3 planting mix or soil	*Pythium*, *Rhizoctonia*, *Fusarium*		Effective when root zone temperature more than 10°C and pH is neutral or acidic.
Rovral 50WP	1 kg/1,000 L	Botrytis grey mould	2	
Microscopic Sulphur 92%	750 g/1,000 L/ha	powdery mildew	1	Maximum of 10 applications/crop cycle. May cause foliar damage.
Supra Captan 80 WDG	63–107 g/100 m^2 as a soil treatment. Use 1.25 kg/1,000 L water and apply at rates of 50–85 L/100 m^2. Work into the upper 7.5–10 cm of soil before planting.	damping off, fungus root rot diseases		

TABLE 15-3. Cucumber Pests

Pesticide	Rate	Pest	Pre-harvest Interval (days)	Remarks
Ambush 50 EC or Pounce EC	200 mL/1,000 L 260 mL/1,000 L	whiteflies	1	Apply to achieve thorough coverage. Repeat as necessary.
Avid	30 mL/100 L	two-spotted spider mite leafminer	3	No more than 5 applications/crop cycle. Apply 600–1,200 mL Avid/ha. Use in sufficient water to obtain coverage (2,000–4,000 L water/ha).
Bioprotec	1.8 L/1,000 L water	cabbage loopers	0	Use diluted spray within 12 hr. Use product within 6 months of manufacture date. Addition of a wetting agent is recommended to improve distribution on foliage.
DDVP 20%EC	6 mL/L	aphids, whiteflies	7	Use cautiously as damage can occur to young flowers, particularly under hot, humid conditions. Thoroughly ventilate before re-entering on the day following treatment.
Dibrom	10 mL/100 m^3 Apply undiluted to cold pipes, then heat to 41°C & close greenhouse for at least 4 hr	aphids, spider mites, whiteflies, mealy bugs, leafrollers	1	May cause injury to flowers. Ventilate greenhouse properly before re-entering.
Dyno-Mite	284 g/ha 1,000 L water/ha	two-spotted spider mites	2	Maximum number of applications per crop cycle is 2. Apply at intervals of at least 28 days.
Foray 48BA	0.6–1.8 L/ha (60–180 mL/1,000 m^2)	cabbage loopers	0	Apply using a high volume spray. Apply at 10 day intervals when loopers first appear. Use 500–1,000 L/ha.
Intercept	16 g/80 L water/1,000 mature plants	whiteflies, aphids	1	Do not apply more than once per season. There may be negative effects on some beneficials.
Insecticidal Soap	1–2 L/100 L	aphids, two-spotted spider mites, whiteflies, earwigs, psyllids		May cause damage to plant under high temperature conditions and when used frequently.
Nicotine Smoke	1 can/300 m^3	aphids, thrips	3	Ventilate greenhouse properly before re-entering.
Sluggo	25–50 kg/ha (2.5–5g/m^2)	slugs and snails		Re-apply bait as needed or at least every 2 weeks if slugs and snails continue to be a problem.
Thiodan/ Thionex 4 EC Thiodan/Thionex 50 WP	1.25–1.5 L/1,000 L/ha 1–1.5 kg/ha	aphids, whiteflies	2	Spray when insects are first observed.
VectoBac 600 L	2–8 L/1,000 L	fungus gnats	0	Do not mix and apply with fertilizers or fungicides containing copper or chlorine as this may neutralize the active ingredients.
Vendex 50W	50 g/100 L	two-spotted spider mites	3	Addition of a suitable spreader-sticker will improve mite control.

TABLE 15–4. Cucumber Diseases

Pesticide	Rate	Disease	Pre-harvest Interval (days)	Remarks
Microscopic sulphur 92%	105 g per 100 L	powdery mildew	1	Apply at weekly intervals. Can cause damage if applied under hot, humid conditions.
Mycostop	As seed treatment — 5–8 g/kg seed	Fusarium damping off	0	
	Immediately after transplanting, apply 5–10 mg/plant or 10–20 mL/plant of 0.05% suspension	damping-off, root & crown rot, wilt caused by *Fusarium & Pythium*		Repeat treatments at intervals of 3–6 weeks depending on disease pressure.
No-Damp	10 mL/1 L	damping-off diseases in seedlings		
Nova 40W	340 g/ha	powdery mildew, gummy stem blight	2	Do not apply more than 6 times per year.
Previcur N	10 mL/10 L of water and apply this solution at rate of 100–200 mL/ plant. Use higher volume for 2nd and 3rd applications.	*Pythium* spp.	14	Maximum of 3 applications per season.
Ridomil Gold 480 EC	Apply 250 mL of solution (0.75–1.25 mL/10 L) to the growing media at base of plant after transplanting.	*Pythium* spp.	21	1 application per crop cycle; **NOT** for cucumbers grown in soil.
Rootshield Drench	60–90 g/100 L	*Pythium, Rhizoctonia, Fusarium*		Effective when root zone temperature more than 10°C and pH is neutral or acidic
Rootshield Granules	600 g/m^3 planting mix or soil	*Pythium, Rhizoctonia, Fusarium*		Effective when root zone temperature more than 10°C and pH is neutral or acidic
Rovral 50WP	1 kg/1,000 L	Botrytis grey mould, gummy stem blight	2	

TABLE 15-5. Pepper Pests

Pesticide	Rate	Pest	Pre-harvest Interval (days)	Remarks
Avid 1.9 EC	30 mL/100 L	two-spotted spider mite	3	No more than 5 applications/crop cycle. Apply 600–1,200 mL Avid/ha. Use in sufficient water to obtain coverage (2,000–4,000 L water/ha). Apply only between February and October when daily light levels are greater than 700 Joules/cm^2/day.
Basudin 500 EC or Diazinon 500 E	230 mL/250 L/4,000 m^2 0.575 L/625 L water	aphids	5	Highly toxic to bees.
Bioprotec	1.8 L/1,000 L water	cabbage loopers	0	Use diluted spray within 12 hr. Use product within 6 months of manufacture date. Addition of a wetting agent is recommended to improve distribution on foliage.
Confirm 240F	0.5 L/ha; apply in 4,000 L water/ha	cabbage looper, European corn borer	3	Ensure good coverage and apply at intervals of approximately 7 days. Do not exceed 4 applications/crop cycle. Re-entry interval is 12 hr.
Dipel 2X DF	75–150 g/250 L/ 4,000 m^2	cabbage loopers		Apply to upper and lower leaf surfaces to runoff. Repeat applications needed with new hatch.
Dyno-Mite	284 g/ha	two-spotted spider mite	3	Maximum number of applications per year is 2.
Endeavor 50WG	100–200 g product/ha using a minimum of 1,000 L water/ha	aphids – green peach and melon aphids	3	Do not exceed 2 applications/crop cycle/year. Do not re-apply for at least 7 days. Use a surfactant for improved coverage.
Foray 48BA	0.6-1.8 L/ha (60–180 mL/1,000 m^2)	cabbage loopers	0	Apply using a high volume spray. Apply at 10 day intervals when loopers first appear. Use 500–1,000 L/ha.
Insecticidal Soap	1–2 L/100 L	aphids, spider mites, whiteflies, earwigs, psyllids	5	May cause damage to plant under high temperature conditions
Intercept	4.1 g/1000 seedlings in a solution application rate of 8 L/100 m^2 of seedling trays.	aphids, whiteflies	3	Apply to 2–3 week old seedlings in flats. One application per growing season. Repellency of bumble bees and negative effects on some beneficials can occur.
Nicotine Smoke	1 can/300 m^3	aphids, thrips	5	Ventilate greenhouse properly before re-entering.
Sluggo	25–50 kg/ha (2.5–5g/m^2)	slugs and snails		Re-apply bait as needed or at least every 2 weeks if slugs and snails continue to be a problem.
Thiodan 4 EC	1.25–1.5 L/1,000 L/ha	lygus bug or tarnished plant bug, aphids	2	Do not apply more than twice per season.
VectoBac 600 L	2–8 L/1,000 L	fungus gnats	0	Do not mix and apply with fertilizers or fungicides containing copper or chlorine as this may neutralize the active ingredients.

TABLE 15-6. Pepper Diseases

Pesticide	Rate	Disease	Pre-harvest Interval (days)	Remarks
Maestro 80DF	1.25 kg/1,000 L Apply 50-85 L/100 m^2	damping-off in seedlings		Work into the upper 7.5-10 cm of soil before planting.
Microscopic Sulphur 92%	543-760 g/1,000 L/ha	powdery mildew		Apply as required on a minimum of 14-day interval for up to 10 applications per crop cycle.
Mycostop	Immediately after transplanting, apply 5-10 mg/plant or 10-20 mL/plant of 0.05% suspension	damping-off, root & crown rot, wilt caused by *Fusarium*; root and stem rot, and wilt caused by *Phytophthora*	0	Repeat treatments at intervals of 3-6 weeks depending on disease pressure
No-Damp	10 mL/1 L	damping-off diseases in seedlings		
Nova	340 g/ha using 1,500-3,000 L water/ha.	powdery mildew	3	Apply as soon as possible after initial infection and again 12 days later when disease pressure warrants control. Maximum number of applications per crop cycle is 3. Re-entry interval is 12 hr.
Supra Captan 80 WDG	63-107 g/100 m^2 as a soil treatment. Use 1.25 kg/1,000 L water and apply at rates of 50-85 L/100 m^2. Work into the upper 7.5-10 cm of soil before planting.	damping-off, fungus root rot diseases		

TABLE 15–7. Lettuce Pests

Pesticide	Rate	Pest	Pre-harvest Interval (days)	Remarks
Bioprotec	1.8 L/1,000 L water	cabbage loopers	0	Use diluted spray within 12 hr. Use product within 6 months of manufacture date. Addition of a wetting agent is recommended to improve distribution on foliage.
Confirm 240F	0.6 L/ha	cabbage loopers	14	Re-entry period is 12 hr. Application interval 10–14 days. Do not exceed 2 applications/crop cycle.
Foray 48BA	0.6–1.8 L/ha (60–180 mL/1,000 m^2)	cabbage loopers	0	Apply using a high volume spray. Apply at 10 day intervals when loopers first appear. Use 500–1,000 L/ha.
Insecticidal Soap	1–2 L/100 L	aphids, spider mites, whiteflies, earwigs, psyllids	0	May cause damage to plant under high temperature conditions.
Malathion 25W	2.75–5.5 kg/ha	aphids, caterpillars, spider mites, thrips, whiteflies	Leaf = 21 Head = 7	Do not apply more than twice per season.
Nicotine Smoke	1 can/300 m^3	aphids, thrips	7	Ventilate greenhouse properly before re-entering.
Sluggo	25–50 kg/ha (2.5–5 g/m^2)	slugs and snails		Re-apply bait as needed or at least every 2 weeks if slugs and snails continue to be a problem.
Thiodan 4 EC	1.25–1.5 L/1,000 L/ha	aphids	14	Only one application per crop; low volume mist or high volume spray.
VectoBac 600 L	2–8 L/1,000 L	fungus gnats	0	Do not mix and apply with fertilizers or fungicides containing copper or chlorine as this may neutralize the active ingredients.

TABLE 15–8. Lettuce Diseases

Pesticide	Rate	Pest	Pre-harvest Interval (days)	Remarks
No-Damp	10 mL/1 L	damping-off diseases in seedlings		
Rovral	1 kg/1,000 L	Botrytis grey mould	14	

16. Appendices

Appendix A. OMAF Staff

Staff	Address	Contact	E-mail
Gillian Ferguson Greenhouse Vegetable IPM Specialist	Greenhouse and Processing Crops Research Centre 2585 County Road 20, Harrow, ON N0R 1G0	Tel: (519) 738-2251, ext. 406 Fax: (519) 738-4565	gillian.ferguson@omaf.gov.on.ca
Shalin Khosla Greenhouse Vegetable Specialist	Greenhouse and Processing Crops Research Centre 2585 County Road 20, Harrow, ON N0R 1G0	Tel: (519) 738-2251, ext. 405 Fax: (519) 738-4565	shalin.khosla@omaf.gov.on.ca

Appendix B. Diagnostic Services

Samples for disease diagnosis, insect or weed identification and nematode counts can be sent to:

Pest Diagnostic Clinic
Laboratory Services Division
University of Guelph
95 Stone Rd. W.
Guelph Ontario, N1H 8J7
tel: (519) 767-6256
fax: (519) 767-6240
e-mail: pdc@lsd.uoguelph.ca

Payment must accompany samples at the time of submission. Submission forms are available at www.uoguelph.ca/pdc.

Fee Schedule

To obtain information on the fee schedule, refer to *www.uoguelph.ca/pdc* or phone the Pest Diagnostic Clinic.

How to Sample for Nematodes

Soil

When to sample

Soil and root samples can be taken at any time of the year that the soil is not frozen. In Ontario, nematode soil population levels are generally at their highest in May and June and again in September and October.

How to sample soil

Use a soil sampling tube, trowel or narrow-bladed shovel to take samples. Sample soil to a depth of 20–25 cm (8–10 in.). If the soil is bare, remove the top 2 cm (1 in.) prior to sampling. A sample should consist of 10 or more subsamples combined. Mix well. Then take a sample of $^1/_2$–1 L (1 pint–1 quart) from this. No one sample should represent more than 2.5 ha (6.25 ac). Mix subsamples in a clean pail or plastic bag.

Sampling pattern

If living crop plants are present in the sample area, take samples within the row and from the area of the feeder root zone (with trees, this is the drip line).

Number of subsamples

Based on the total area sampled:

500 m^2 (5,400 ft^2)	10 subsamples
500 m^2–0.5 ha (5,400 ft^2–1.25 ac)	25 subsamples
0.5 ha–2.5 ha (1.25–6.25 ac)	50 subsamples

Roots

From small plants, sample the entire root system plus adhering growing media. For large plants, obtain 10–20 g ($^1/_2$–1 oz.) fresh weight from the feeder root zone and submit.

Problem areas

Take growing media and root samples from the margins of the problem area where the plants are still living. If possible, also take samples from healthy plants. In addition, take both growing media and root samples from problem and healthy areas in the same vicinity.

Sample handling

Soil samples

Place in plastic bags as soon as possible after collecting.

Root samples

Place in plastic bags with moist growing media soon after collecting.

Storage

Store samples at 5°C–10°C (40°C–50°F) and do not expose them to direct sunlight or extreme heat or cold (freezing). **Only living nematodes can be counted. Accurate counts depend on proper handling of samples.**

Submitting Plant for Disease Diagnosis or Identification

Sample submission forms

Forms can be obtained from your local Ontario Ministry of Agriculture and Food office. Carefully fill in all of the categories on the form. In the space provided, draw the most obvious symptom and the pattern of the disease in the greenhouse. It is important to include the cropping history of the area for the past 3 years and this year's pesticide use records.

Choose a complete, representative sample showing early symptoms. Submit as much of the plant as is practical, including the root system, or several plants showing a range of symptoms. If symptoms are general, collect the sample from an area where they are of intermediate severity. Completely dead material is usually inadequate for diagnosis. With plant specimens submitted for identification, include at least a 20–25-cm sample of the top portion of the stem with lateral buds, leaves, flowers or fruits in identifiable condition. Wrap plants in newspaper and put in a plastic bag. Tie the root system off in a separate plastic bag to avoid drying out and solution contaminating the leaves. Do **NOT** add moisture, as this encourages decay in transit. Cushion specimens and pack in a sturdy box to avoid damage during shipping. Avoid leaving specimens to bake or freeze in a vehicle or in a location where they could deteriorate.

Delivery

Deliver to the Pest Diagnostic Clinic as soon as possible by first class mail or by courier at the beginning of the week.

Submitting Insect Specimens for Identification

Collecting samples

Place dead, hard-bodied insects and spiders in vials or boxes and cushion with tissues or cotton. Place soft-bodied insects and caterpillars in vials containing alcohol. Do not use water, as this results in rot. Do not tape insects to paper or send them loose in an envelope.

Place live insects in a container with enough plant "food" to support them during transit. Be sure to write "live" on the outside of the container.

APPENDIX C. Phyosanitary Certificates

Phytosanitary certificates may be required by importing countries. A phytosanitary certificate is a certificate indicating that a shipment is free from recognized or quarantinable pests. The importing country will list the pests or conditions associated with certification. Knowing the rules in advance will avoid situations where your perishable crop may be held up before entry.

Phytosanitary certificates can be obtained through the Canadian Food Inspection Agency (CFIA) at one of the regional offices listed in Appendix D.

APPENDIX D. Other Contacts

UNIVERSITY OF GUELPH
Main Campus
Guelph, N1G 2W1
(519) 824-4120
www.uoguelph.ca

Alfred College
Alfred, K0B 1A0
(613) 679-2218
www.alfredc.uoguelph.ca/

Kemptville College
Kemptville, K0G 1J0
(613) 258-8336
www.kemptvillec.uoguelph.ca

Ridgetown College
Ridgetown, N0P 2C0
(519) 674-1500
www.ridgetownc.on.ca

Department of Plant Agriculture
www.plant.uoguelph.ca

Department of Plant Agriculture
Kettleby
1125 Woodchopper's Lane, R.R. # 1
Kettleby, L0G 1J0
(905) 775-3783

Department of Plant Agriculture,
Simcoe
Box 587 Blue Line Rd.
Simcoe, N3Y 4N5
(519) 426-7127

Department of Plant Agriculture,
Vineland
Box 7000, 4890 Victoria Ave. N.
Vineland Station, L0R 2E0
(905) 562-4141

Lab Services Division
www.uoguelph.ca/labserv/

Pesticide and Trace Contaminants
P.O. Box 3650, 95 Stone Rd. W.
Guelph, N1H 8J7
(519) 767-6200

Pest Diagnostic Clinic
95 Stone Rd. W.
Guelph, N1H 8S7
(519) 767-6256
www.uoguelph.ca/pdc

AGRICULTURE & AGRI-FOOD CANADA

Research Centres

Eastern Cereals and Oilseeds
Research Centre
960 Carling Avenue, Ottawa, K1A
0C6
(613) 759-1952
http://res2agr.ca/ecorc/index_e.htm

Greenhouse and Processing Crops
Research Centre
Harrow, N0R 1G0
(519) 738-2251
http://res2.agr.ca/harrow/

Southern Crop Protection and Food
Research Centre
http://res2.agr.ca/london/pmrc/
pmrchome.html

1391 Sandford St.
London, N5V 4T3
(519) 457-1470

Vineland Research Farm
4902 Victoria Ave. N.
Vineland, L0R 2E0
(905) 562-4113

Delhi Research Farm
Box 186 Schafer Rd.
Delhi, N4B 2W9
(519) 582-1950

CANADIAN FOOD INSPECTION AGENCY
www.cifa-acia.agr.ca

Regional Offices (Plant Protection)

Belleville
345 College St. E.
Belleville, K8N 5S7
(613) 969-3333

Brantford
Federal Building, Dalhousie &
Queen St.
P.O. Box 637
Brantford, N3T 5P9
tel (519) 751-8157

Hamilton
709 Main St. W., 101
Hamilton, L8S 1A2
(905) 572-4152

London
1200 Commissioners Rd. E., Unit 19
London, N5Z 4R3
(519) 691-1300

Niagara Falls
(Mailing address)
R.R #1 P.O. Box #7
Niagara on the Lake, L0S 1J0
(Street address)
14154 Niagara River Parkway, Unit #5
Niagara on the Lake
(905) 262-5331

Ottawa District
3 Observatory Crescent, Bldg.
#3 Central
Experimental Farm, Ottawa, K1A 0C9
(613) 759-1571

Toronto Office
401 Champagne Dr., Unit 1
Downsview, M3J 2C6
(416) 954-1714

Windsor
441 University Ave. W., Suite 208
Windsor, N9A 5P9
(519) 252-7095

AGRICORP (Crop Insurance)
Customer Action Centre
1-888-AGRI-999
(1-888-247-4999)
P.O. Box 3660, Station Central
Guelph, N1H 8M4
www.agricorp.com

APPENDIX E. Accredited Soil Testing Labs in Ontario

The following labs are accredited to perform soil tests for pH, buffer pH, P, K, Mg and Nitrate-N on Ontario soils.

Laboratory Name	Address	Telephone/Fax/e-mail	Contact
A & L Canada Laboratories East. Inc.	2136 Jetstream Road London, Ont. N5V 3P5	tel: (519) 457-2575 fax: (519) 457-2664 e-mail: aginfo@al-labs-can.com web site: www.al-labs-can.com	Greg Patterson Ian McLachlin
Accutest Laboratories	146 Colonnade Road, Unit #8 Nepean, Ont. K2E 7Y1	tel: (613) 727-5692 fax: (613) 727-5222 e-mail: phaulena@accutestlabs.com web site: www.accutestlabs.com	Lorna Wilson Peter Haulena
Agri-Food Laboratories	503 Imperial Road, Unit #1 Guelph, Ont. N1H 6T9	tel: (519) 837-1600 1-800-265-7175 fax: (519) 837-1242 e-mail: lab@agtest.com web site: www.agtest.com	Dale Cowan Nora Wilson
Brookside Laboratories, Inc.	301 South Main Street New Knoxville, Ohio 45871	tel: (419) 753-2448 fax: (419) 753-2949 e-mail: nfisher@blinc.com	Nicole Fisher Mark Flock
Soil and Nutrient Laboratory	University of Guelph P.O. Box 3650, 95 Stone Road West, Guelph, Ont. N1H 2W1	tel: (519) 767-6226 fax: (519) 767-6240 e-mail: vkerslak@lsd.uoguelph.ca	Virginia Kerslake
Stratford Agri Analysis (A Daco Laboratories Ltd.)	1131 Erie St., Box 760 Stratford, Ont. N5A 6W1	tel: (519) 273-4411 1-800-323-9089 fax: (519) 273-4411 e-mail: saa@dacolabs.com	Dale Peters Keith Lemp

There is no official accreditation in Ontario for tissue analysis, but all of the accredited soil testing labs are monitored for proficiency on tissue analysis.

APPENDIX F. Ontario Ministry of the Environment Pesticide Control Offices

Region/County	Address	Telephone/Fax
Central Region Toronto, Halton, Peel, York, Durham	5775 Yonge Street, 8th Floor Toronto, Ont. M2M 4J1	tel (416) 326-6700 toll free 1-800-810-8048 fax (416) 325-6347
West-Central Region Haldimand-Norfolk, Niagara, Hamilton-Wentworth, Dufferin, Wellington, Waterloo, Brant	Ontario Government Building 119 King Street West, 12th Floor Hamilton, Ont. L8P 4Y7	tel (905) 521-7640 toll free1-800-668-4557 fax (905) 521-7820
Eastern Region Frontenac, Hastings, Lennox & Addington, Prince Edward, Leeds & Grenville, Prescott & Russell, Stormont/Dundas & Glengarry, Peterborough, Victoria, Northumberland, Renfrew, Ottawa-Carleton, Lanark, District of Nipissing (Townships of Airy, Murchison, Dickens, Lyell and Sabine)	133 Dalton Avenue Kingston, Ont. K7L 4X6	tel (613) 549-4000 toll free 1-800-267-0974 (in Eastern region only) fax (613) 548-6908
Southwestern Region Elgin, Middlesex, Oxford, Essex, Kent, Lambton, Bruce, Grey, Huron, Perth, Simcoe	659 Exeter Road, 2nd Floor London, Ont. N6E 1L3	tel (519) 873-5000 toll free1-800-265-7672 fax (519) 873-5020
Northern Region East Manitoulin, Nipissing, Parry Sound, Sudbury, Algoma East, Cochrane East, Haliburton, Muskoka	199 Larch Street, Suite 1101 Sudbury, Ont. P3E 5P9	tel (705) 564-3249 fax (705) 564-4180
Northern Region West Kenora, Rainy River, Thunder Bay, Algoma West, Cochrane West	435 James St. S., Suite 331 Thunder Bay, Ont. P7E 6S7	tel(807) 475-1712 toll free1-800-875-7772 fax(807) 475-1754
Standards Development Branch	Pesticides Section 40 St. Clair Avenue West, 7th Floor Toronto, Ont. M4V 1M2	tel (416) 327-5519 fax (416) 327-2936
Approvals Branch	Pesticides Licensing 2 St. Clair Avenue West, 12A Floor Toronto, Ont. M4V 1L5	tel (416) 314-8001 toll free 1-800-461-6290 fax (416) 314-8452

APPENDIX G. The Metric System

Metric Units

Linear Measures (length)		
10 millimetres (mm)	=	1 centimetre (cm)
100 centimetres (cm)	=	1 metre (m)
1,000 metres	=	1 kilometre (km)
Square Measures (area)		
100 m x 100 m = 10,000 m^2	=	1 hectare (ha)
100 ha	=	1 square kilometre (km^2)
Cubic Measures (volume)		
Dry Measure		
1,000 cubic millimetres (mm^3)	=	1 cubic centimetre (cm^3)
1,000,000 cm^3	=	1 cubic metre (m^3)
Liquid Measure		
1,000 millilitres (mL)	=	1 litre (L)
100 L	=	1 hectolitre (hL)
Weight-Volume Equivalents (for water)		
(1.00 kg) 1,000 grams	=	1 litre (1.00 L)
(0.50 kg) 500 g	=	500 mL (0.50 L)
(0.10 kg) 100 g	=	100 mL (0.10 L)
(0.01 kg) 10 g	=	10 mL (0.01 L)
(0.001 kg) 1 g	=	1 mL (0.001 L)
Weight Measures		
1,000 milligrams (mg)	=	1 gram (g)
1,000 g	=	1 kilogram (kg)
1,000 kg	=	1 tonne (t)
1 mg/kg	=	1 part per million (ppm)
Dry–Liquid Equivalents		
1 cm^3	=	1 mL
1 m^3	=	1000 L
Metric Conversions		
5 mL	=	1 tsp
15 mL	=	1 tbsp
28.5 mL	=	1 fl. oz.

Application Rate Conversations

Metric to Imperial (Approximate)		
litres per hectare x 0.09	=	gallons per acre
litres per hectare x 0.36	=	quarts per acre
litres per hectare x 0.71	=	pints per acre
millilitres per hectare x 0.015	=	fluid ounces per acre
grams per hectare x 0.015	=	ounces per acre
kilograms per hectare x 0.89	=	pounds per acre
tonnes per hectare x 0.45	=	tons per acre
Imperial to Metric (Approximate)		
gallons per acre x 11.23	=	litres per hectare (L/ha)
quarts per acre x 2.8	=	litres per hectare (L/ha)
pints per acre x 1.4	=	litres per hectare (L/ha)
fluid ounces per acre x 70	=	millilitres per hectare (mL/ha)
tons per acre x 2.24	=	tonnes per hectare (t/ha)
pounds per acre x 1.12	=	kilograms per hectare (kg/ha)
ounces per acre x 70	=	grams per hectare (g/ha)

Liquid Equivalents

Litres/Hectare		*Approximate Gallons/Acre*
50 L/ha	=	5 gal./acre
100 L/ha	=	10 gal./acre
150 L/ha	=	15 gal./acre
200 L/ha	=	20 gal./acre
250 L/ha	=	25 gal./acre
300 L/ha	=	30 gal./acre

Dry Weight Equivalents

Grams or Kilograms / Hectare		*Ounces or Pounds /Acre*
100 g/ha	=	1 1/2 oz./acre
200 g/ha	=	3 oz./acre
300 g/ha	=	4 1/4 oz./acre
500 g/ha	=	7 oz./acre
700 g/ha	=	10 oz./acre
1.10 kg/ha	=	1 lb./acre
1.50 kg/ha	=	1 1/4 lb./acre
2.00 kg/ha	=	1 3/4 lb./acre
2.50 kg/ha	=	2 1/4 lb./acre
3.25 kg/ha	=	3 lb./acre
4.00 kg/ha	=	3 1/2 lb./acre
5.00 kg/ha	=	4 1/2 lb./acre
6.00 kg/ha	=	5 1/4 lb./acre
7.50 kg/ha	=	6 3/4 lb./acre
9.00 kg/ha	=	8 lb./acre
11.00 kg/ha	=	10 lb./acre
13.00 kg/ha	=	11 1/2 lb./acre
15.0 kg/ha	=	13 1/2 lb./acre

Conversion Tables — Metric to Imperial

Length		
1 millimetre (mm)	=	0.04 inch
1 centimetre (cm)	=	0.40 inch
1 metre (m)	=	39.40 inches
1 metre (m)	=	3.28 feet
1 metre (m)	=	1.09 yards
1 kilometre (km)	=	0.62 mile
Area		
1 square centimetre (cm^2)	=	0.16 square inch
1 square metre (m^2)	=	10.77 square feet
1 square metre (m^2)	=	1.20 square yards
1 square kilometre (km^2)	=	0.39 square mile
1 hectare (ha)	=	107,636 square feet
1 hectare (ha)	=	2.5 acres
Volume (dry)		
1 cubic centimetre (cm^3)	=	0.061 cubic inch
1 cubic metre (m^3)	=	1.31 cubic yards
1 cubic metre (m^3)	=	35.31 cubic feet
1,000 cubic metres (m^3)	=	0.81 acre-foot
1 hectolitre (hL)	=	2.8 bushels
Volume (liquid)		
1 millilitre (mL)	=	0.035 fluid ounce
1 litre (L)	=	1.76 pints
1 litre (L)	=	0.88 quart
1 litre (L)	=	0.22 gallon (Imp.)
1 litre (L)	=	0.26 gallon (U.S.)
Weight		
1 gram (g)	=	0.035 ounce
1 kilogram (kg)	=	2.21 pounds
1 tonne (t)	=	1.10 short tons
1 tonne (t)	=	2.205 pounds
Pressure		
1 kilopascal (kPa)	=	0.15 pounds/$in.^2$
Speed		
1 metre per second	=	3.28 feet per second
1 metre per second	=	2.24 miles per hour
1 kilometre per hour	=	0.62 mile per hour
Temperature		
°F	=	(°C X 9/5) + 32

Conversion Tables — Imperial to Metric

Length		
1 inch	=	2.54 cm
1 foot	=	0.30 m
1 yard	=	0.91 m
1 mile	=	1.61 km
Area		
1 square foot	=	0.09 m^2
1 square yard	=	0.84 m^2
1 acre	=	0.40 ha
Volume (dry)		
1 cubic yard	=	0.76 m^3
1 bushel	=	36.37 L
Volume (liquid)		
1 fluid ounce (Imp.)	=	28.41 mL
1 pint (Imp.)	=	0.57 L
1 gallon (Imp.)	=	4.55 L
1 gallon (U.S.)	=	3.79 L
Weight		
1 ounce	=	28.35 g
1 pound	=	453.6 g
1 ton	=	0.91 tonne
Pressure		
1 pound per square inch	=	6.90 kPa
Temperature		
°C	=	(°F – 32) x 5/9

Handy Metric Conversion Factor
Litres per hectare x 0.4 = litres per acre
Kilograms per hectare x 0.4 = kilograms per acre

Abbreviations

%	= per cent (by weight)	F	= flowable	mL	= millilitre
ai	= active ingredient	g	= gram	mm	= millimetre
AP	= agricultural powder	Gr	= granules, granular	m/s	= metres per second
cm	= centimetre	ha	= hectare	SC	= sprayable concentrate
cm^2	= square centimetre	kg	= kilogram	SP	= soluble powder
DG	= dispersible granular	km/h	= kilometres per hour	t	= tonne
DP	= dispersible powder	kPa	= kilopascal	W	= wettable (powder)
E	= emulsifiable	L	= litre	WDG	= water dispersible granular
e.g.	= for example	m	= metre	WP	= wettable powder
EC	= emulsifiable concentrate	m^2	= square metre		

NOTES

Colour Plates

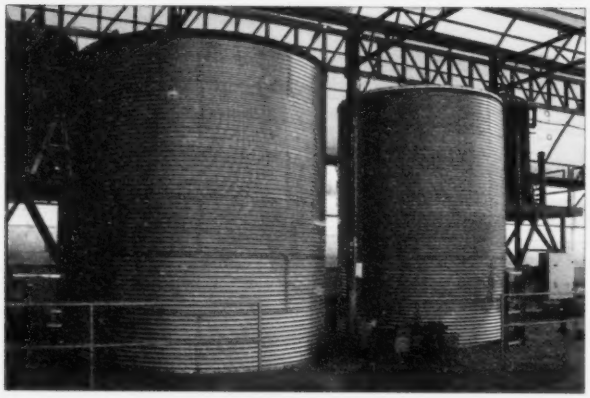


PLATE 1. Above ground nutrient solution tank.

PLATE 2. Below ground nutrient solution tank.

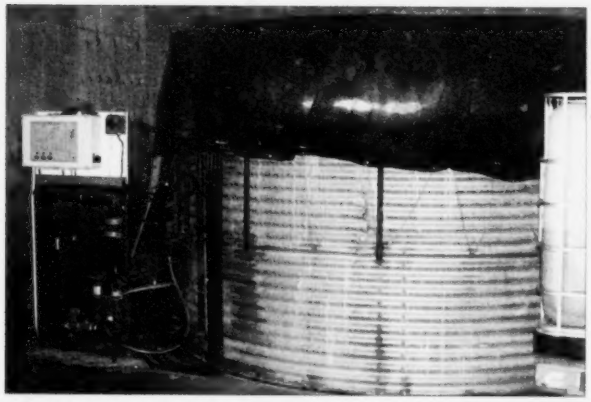


PLATE 3. Lava filtration system.

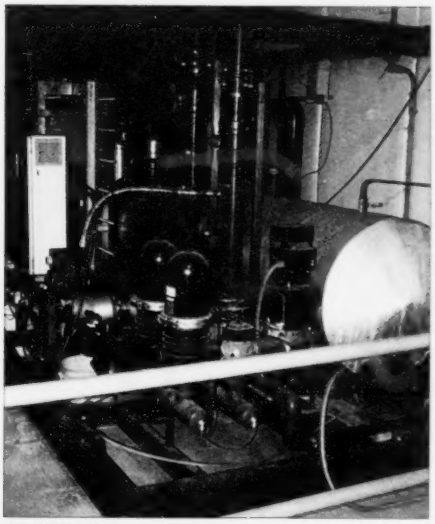


PLATE 4. Heat pasteurization unit.

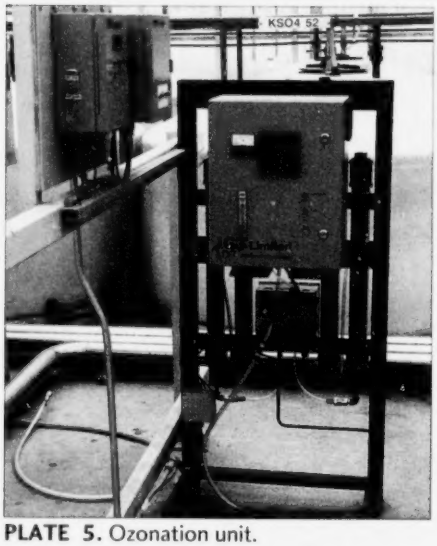


PLATE 5. Ozonation unit.

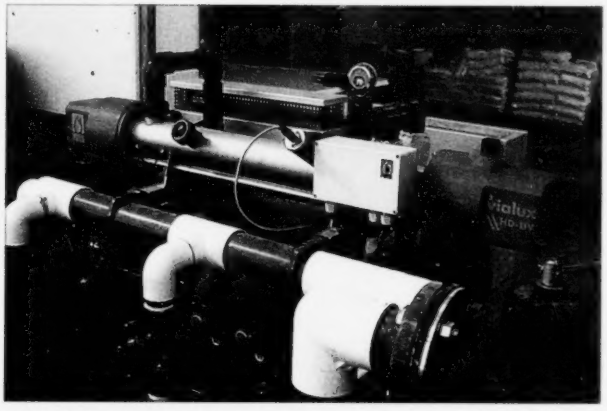


PLATE 6. Ultraviolet filtration.

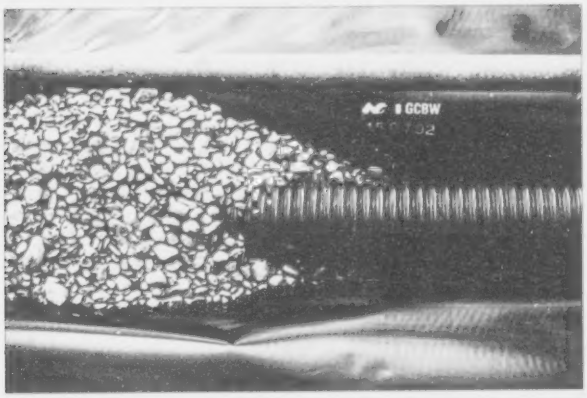


PLATE 7. Basic set up for rockwool production.

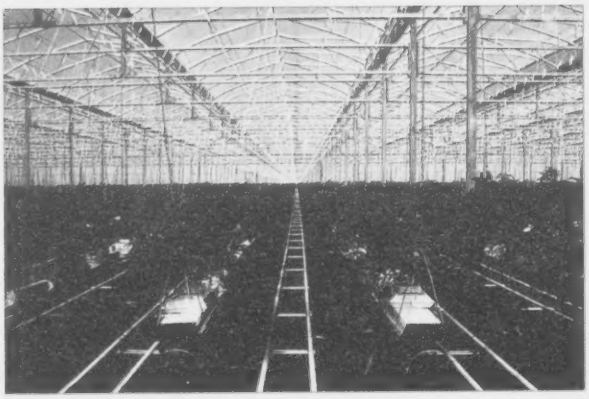


PLATE 8. Raised trough system.

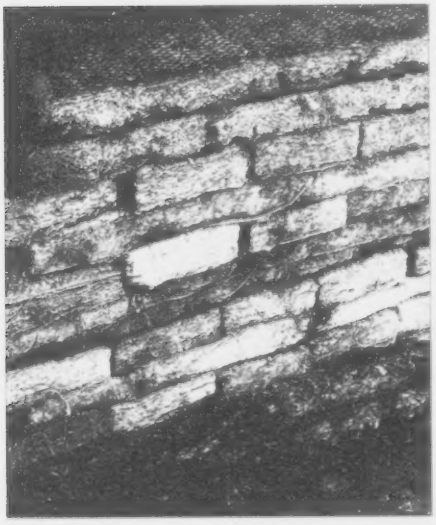


PLATE 9. Rockwool slabs ready for steaming.

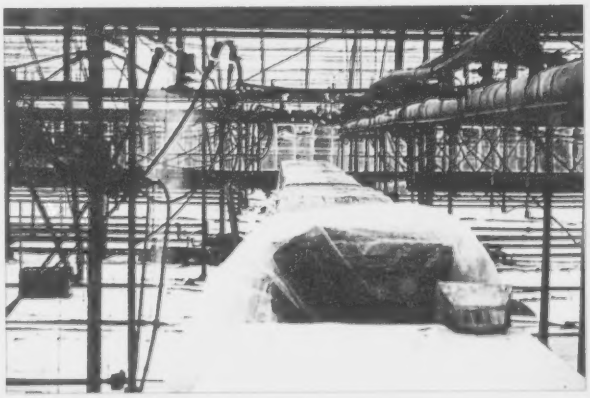


PLATE 10. Steaming of rockwool slabs.

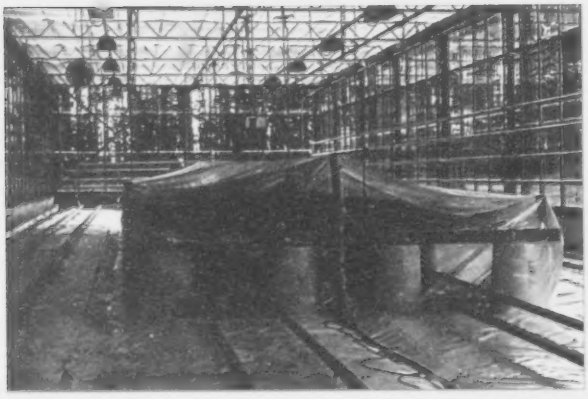


PLATE 11. Set up for seed germination.

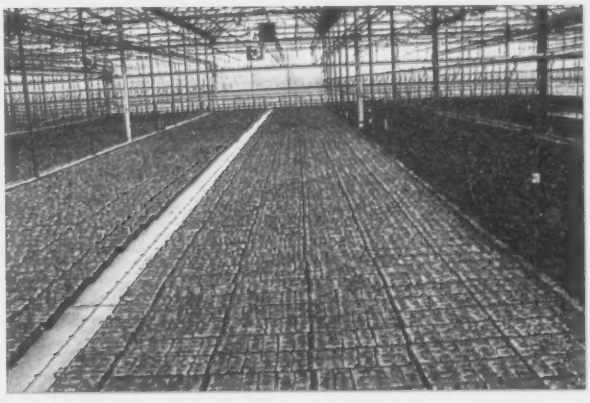


PLATE 12. Transplant raising.

PLATE 13. see next page

PLATE 14. (a) Flower development — stalk slightly too long.

PLATE 14. (b) Split cluster due to low night temperature at the early bud development stage.

PLATE 15. Tomato truss too long resulting in kinking of stalk.

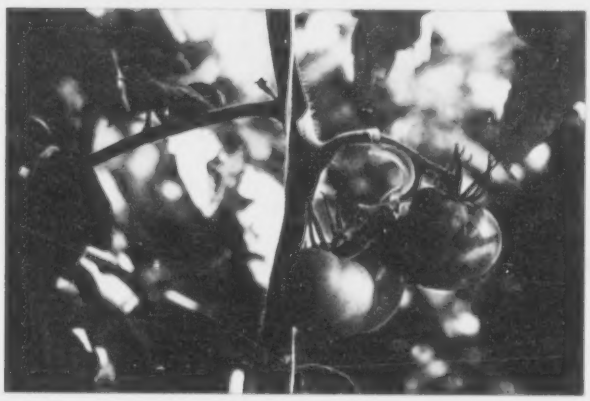


PLATE 16. Truss support to prevent kinking.

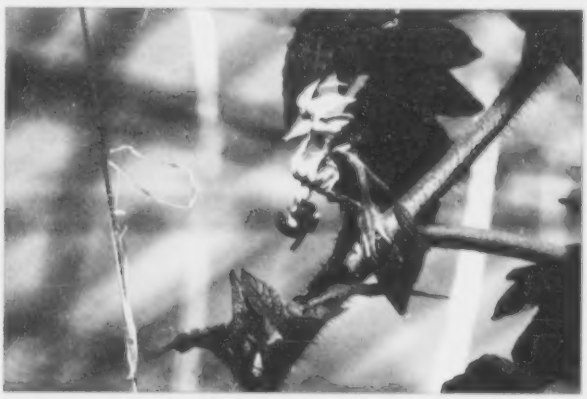
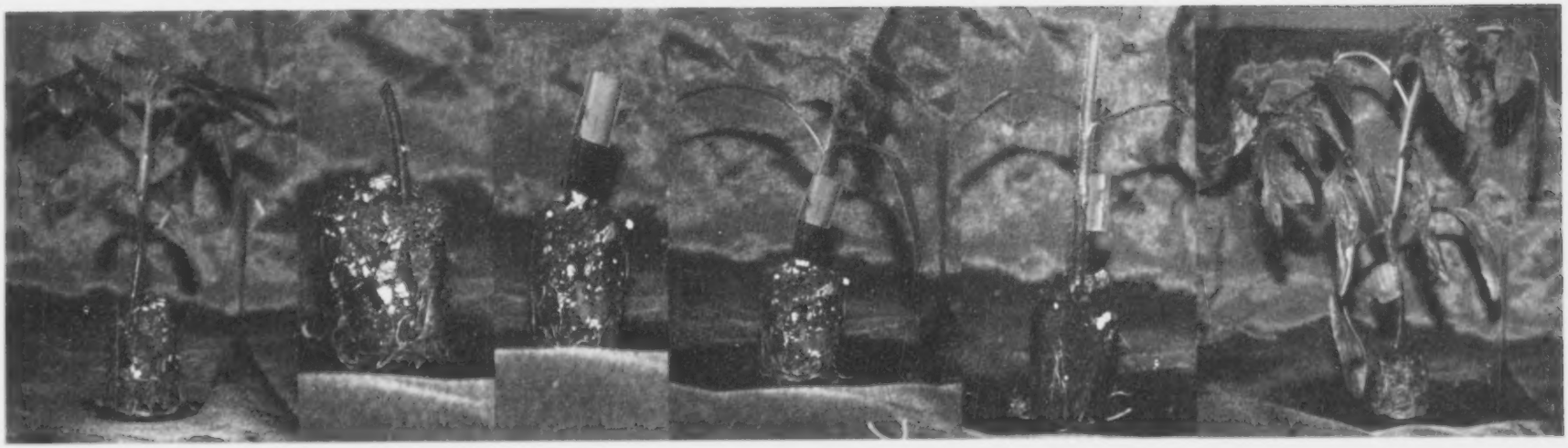


PLATE 17. Bumblebee visiting tomato flower.



Rootstock

Rootstock with top removed and clip added

Scion placed into clip

Finished graft with growing point removed resulting in two stems

PLATE 13. Japanese top graft for tomato.

PLATE 18. Tomato flower showing marks caused by bumblebee visit — an indication of good pollination.

PLATE 19. Cucumber ready for transplanting.

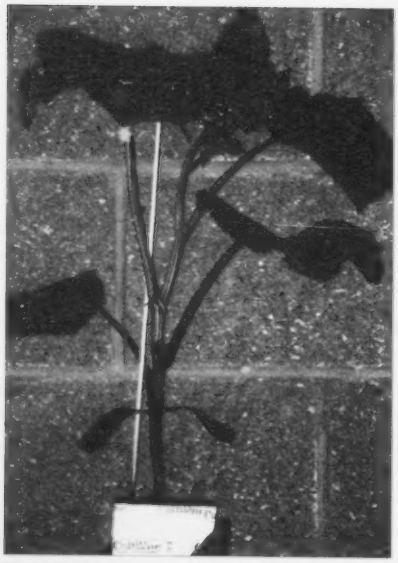


PLATE 20. Young pepper plant showing split stem and first flower (king flower) on the first level.

PLATE 21. Sunscald.

PLATE 22. Sunburn on pepper surface due to poor canopy and direct light on fruit surface.

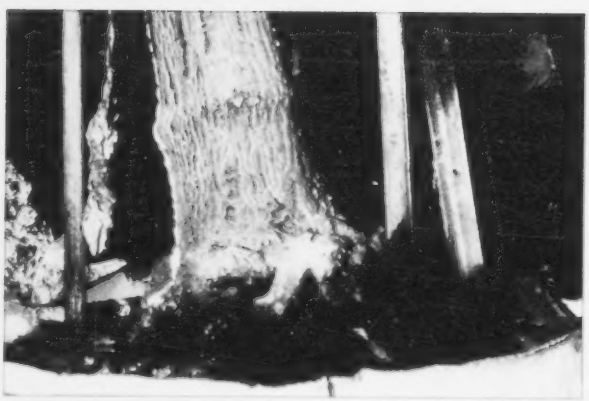


PLATE 23. Elephant's foot.

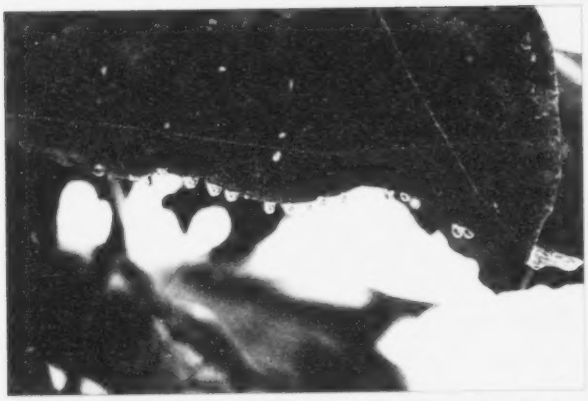


PLATE 24. High humidity in the greenhouse causing water condensation. This increases incidence of gummy stem blight, Botrytis and Penicillium stem rot.

PLATE 25. Damping-off.

PLATE 26. Fusarium crown and root rot.

PLATE 27. Grey mould.

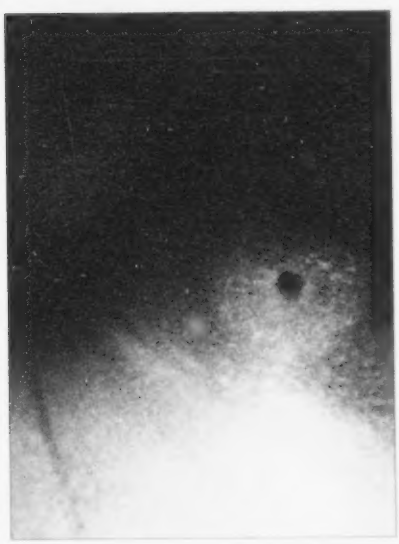


PLATE 28. Grey mould ghost spot.

PLATE 29. Powdery mildew.

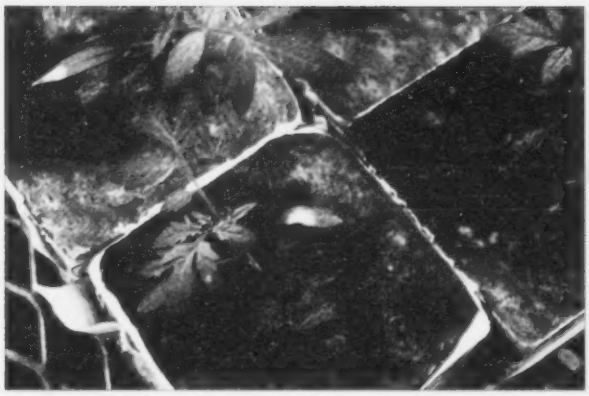


PLATE 30. Powdery mildew.

PLATE 31. Bacterial canker — one sided wilt.

PLATE 32. Bacterial canker — fruit mottling.

PLATE 33. Bacterial stem rot.

PLATE 34. Leaf symptoms of Pepino mosaic virus in tomato.

PLATE 35. Leaf symptoms of Pepino mosaic virus in tomato.

PLATE 36. Leaf symptoms due to Pepino mosaic virus in tomato.

PLATE 37. Leaf symptoms of tomato spotted wilt virus in tomato.

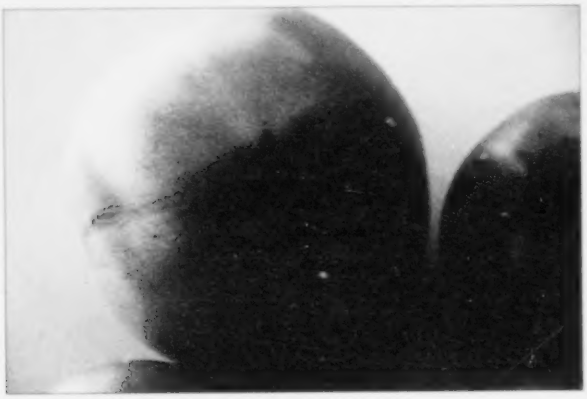


PLATE 38. Blossom end rot.

PLATE 39. Blotchy ripening due to low potassium.

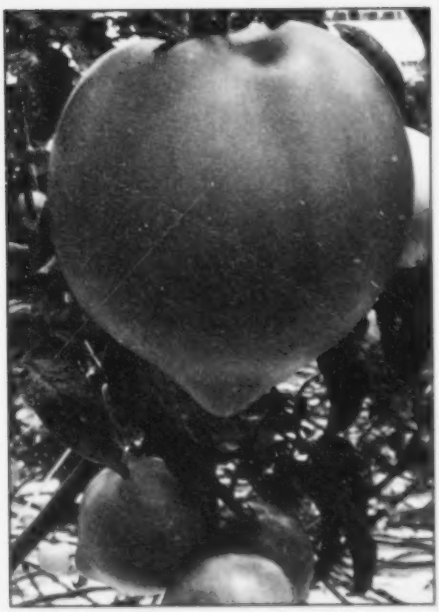


PLATE 40. Tomato pointy fruit.

PLATE 41. Magnesium deficiency.

PLATE 42. Environmental stress resulting in poor Ca and K movement to leaf's edge.

PLATE 43. Iron deficiency.

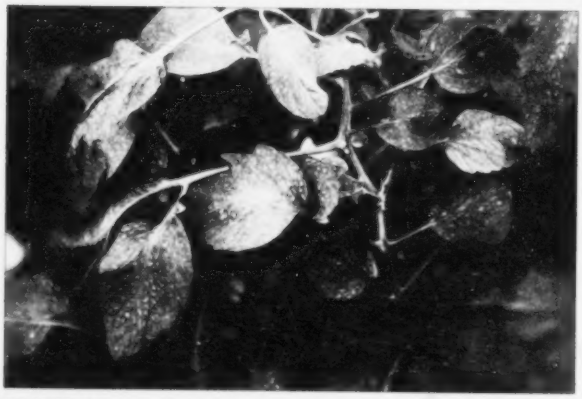


PLATE 44. Iron deficiency due to poor root environment as a result of overwatering.

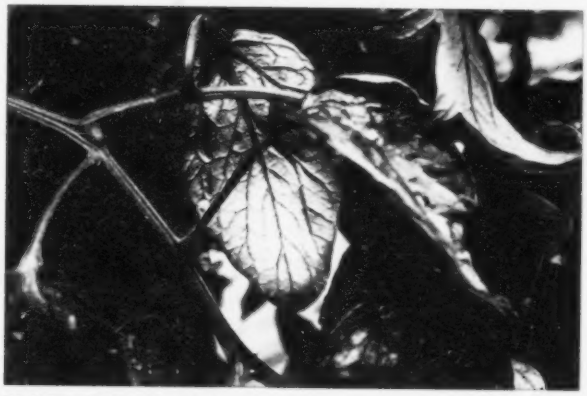


PLATE 45. Boron deficiency.

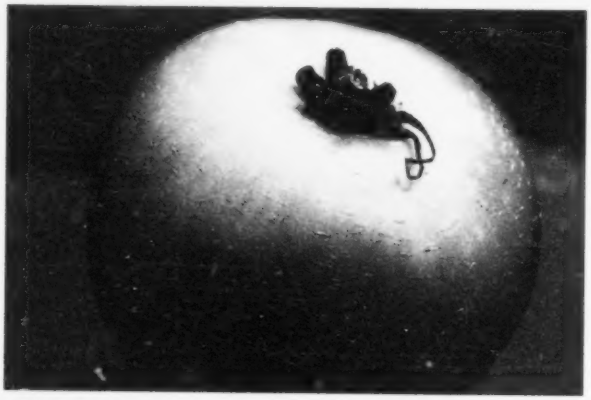


PLATE 46. Russetting.

PLATE 47. Green shoulder.

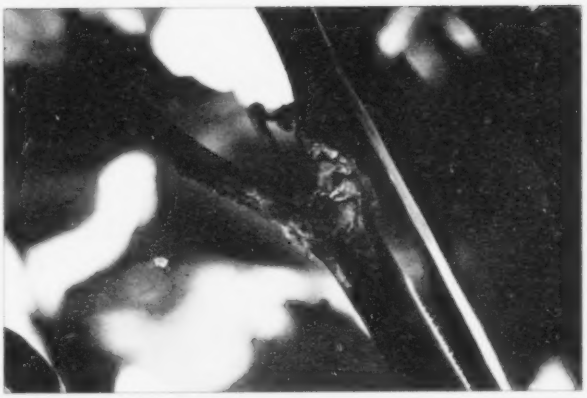


PLATE 48. Grey mould.

PLATE 49. Gummy stem blight on stem.

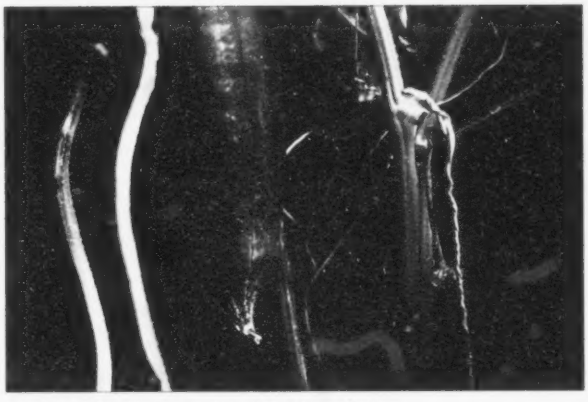


PLATE 50. Gummy stem blight on fruit.

PLATE 51. Penicillium stem rot.

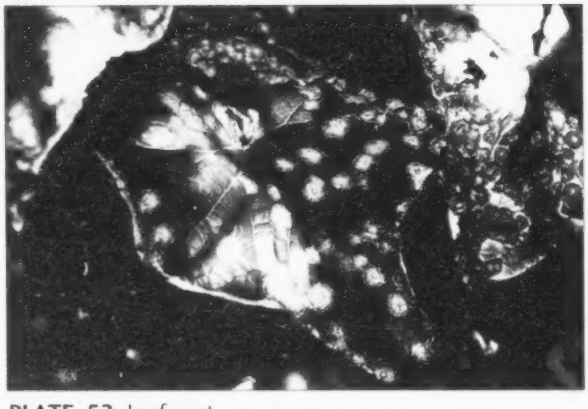


PLATE 52. Leaf spot.

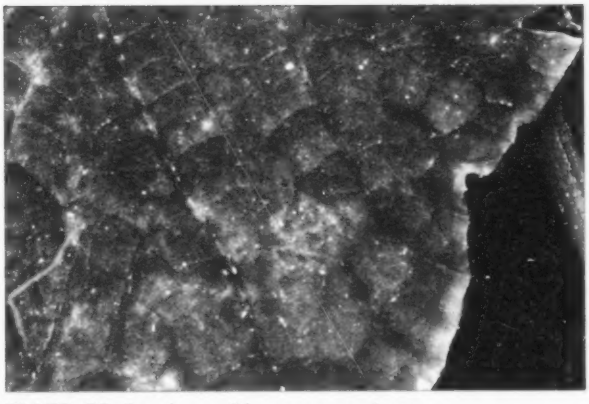


PLATE 53. Powdery mildew on cucumbers.

PLATE 54. Fusarium wilt of cucumbers.

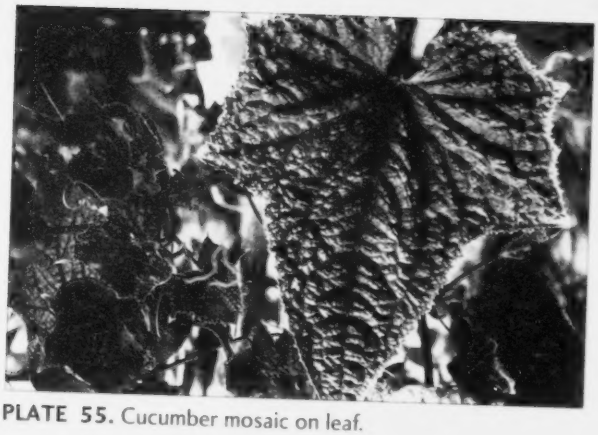


PLATE 55. Cucumber mosaic on leaf.

PLATE 56. Cucumber mosaic on fruit.

PLATE 57. Early symptoms of cucumber necrosis virus in cucumber.

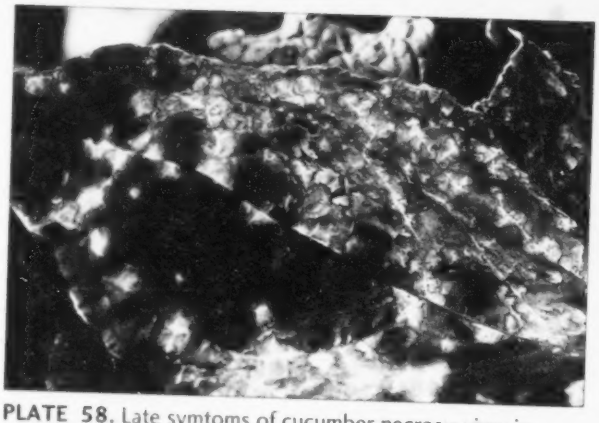


PLATE 58. Late symtoms of cucumber necrosis virus in cucumber.

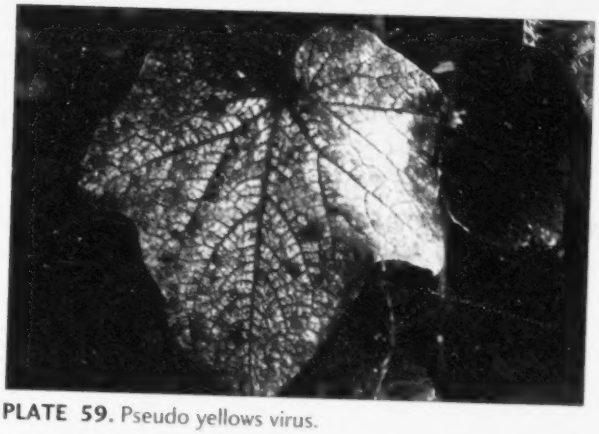


PLATE 59. Pseudo yellows virus.

PLATE 60. Loss of growing point caused by calcium deficiency due to low calcium supply and rapid growth on young cucumber shoots.

PLATE 61. Young cucumber leaf showing iron deficiency symptoms due to rapid growth and heavy fruit load.

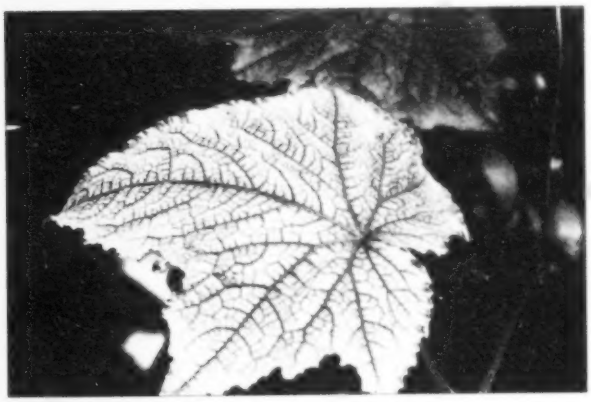


PLATE 62. Iron deficiency.

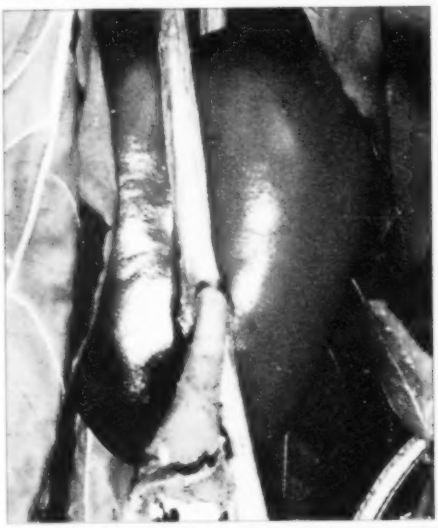


PLATE 63. Botrytis.

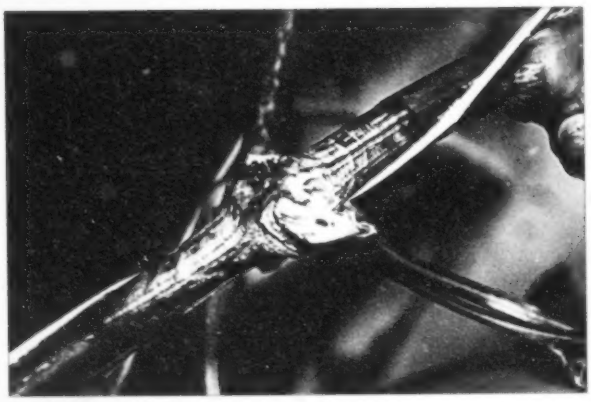


PLATE 64. Fusarium stem and fruit rot.

PLATE 65. Fusarium stem and fruit rot.

PLATE 66. Powdery mildew.

PLATE 67. Bacterial soft rot of peppers.

PLATE 68. Pepper mild mottle virus.

PLATE 69. Leaf symptoms of tomato spotted wilt virus in pepper.

PLATE 70. Blossom end rot.

PLATE 71. Fruit cracking due to internal growth.

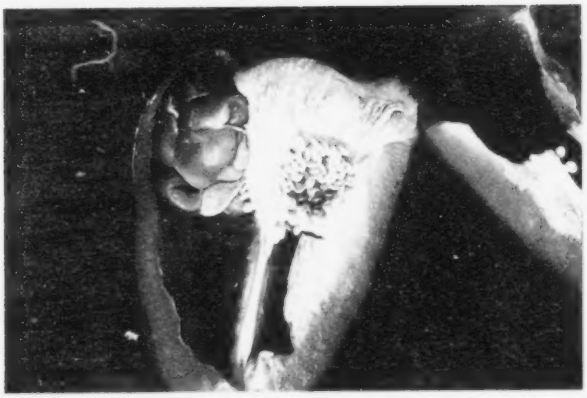


PLATE 72. Fruit cracking due to internal growth (cross section).

PLATE 73. Silvering on pepper fruit.

PLATE 74. Manganese deficiency.

PLATE 75. Boron deficiency.

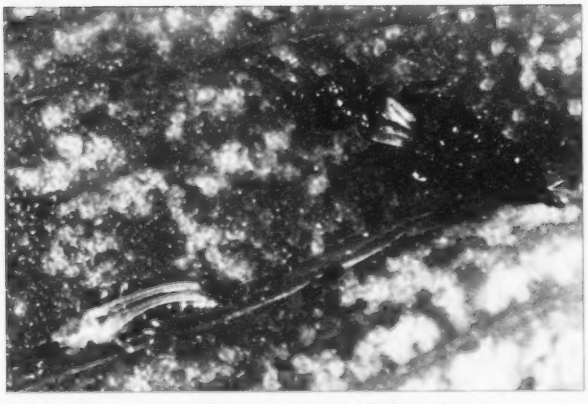


PLATE 76. Western flower thrips and Echinothrips.

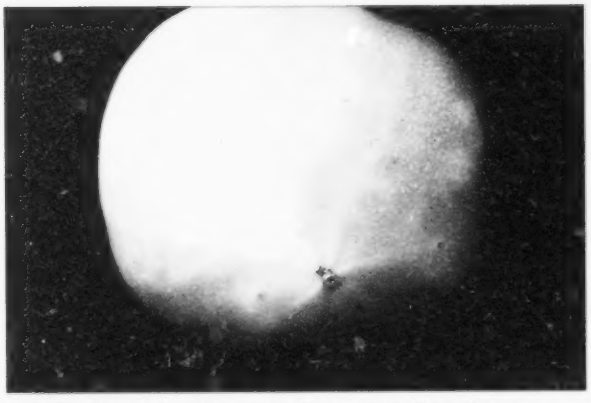


PLATE 77. Thrips damage to fruit, oviposition damage.

PLATE 78. Tomato spotted wilt virus.

PLATE 79. Whiteflies.

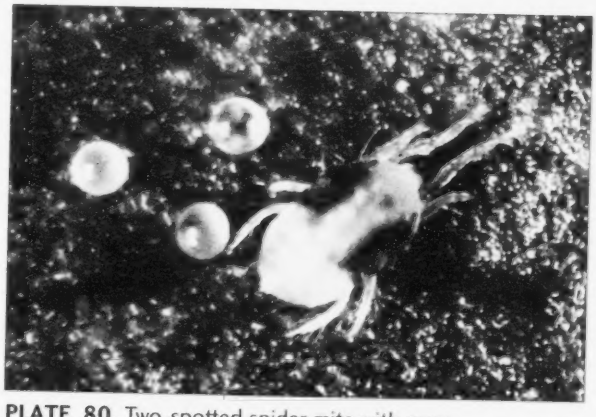


PLATE 80. Two-spotted spider mite with eggs.

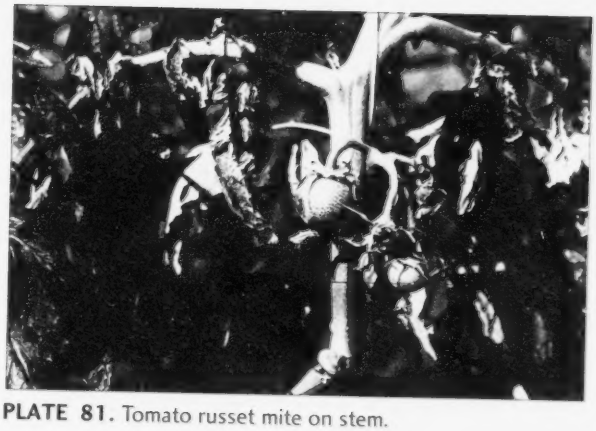


PLATE 81. Tomato russet mite on stem.

PLATE 82. Feeding damage symptoms due to cyclamen mite on peppers.

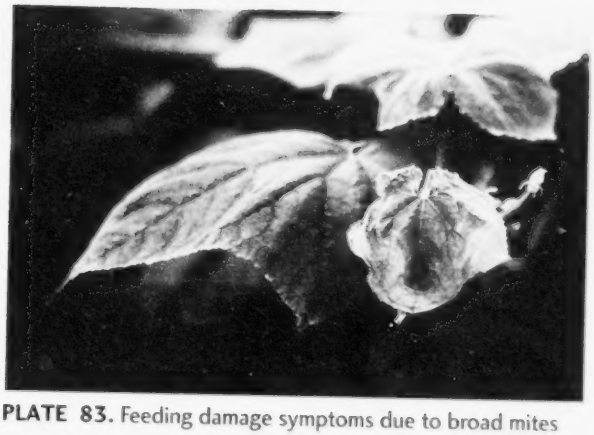


PLATE 83. Feeding damage symptoms due to broad mites on peppers.

PLATE 84. Green peach aphids.

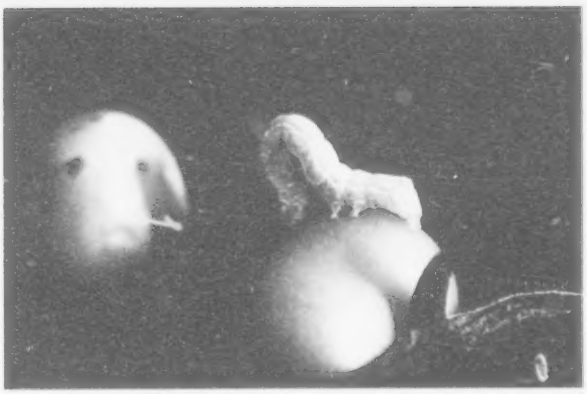


PLATE 85. Cabbage loopers.

PLATE 86. Lygus bug.

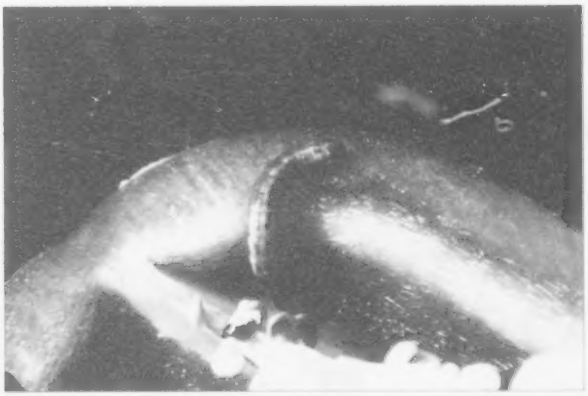


PLATE 87. European corn borer.

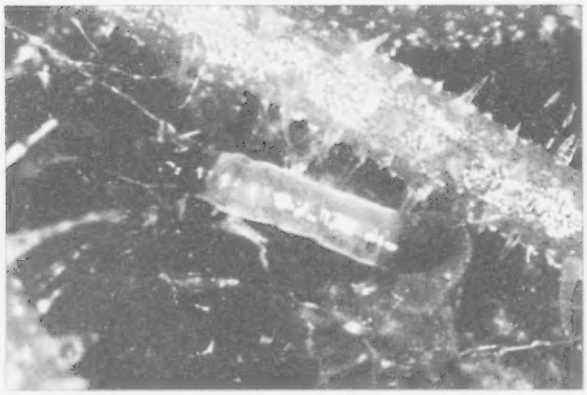


PLATE 88. Fungus gnat.

PLATE 89. Adult rove beetle.

PLATE 90. Tomato pinworm.

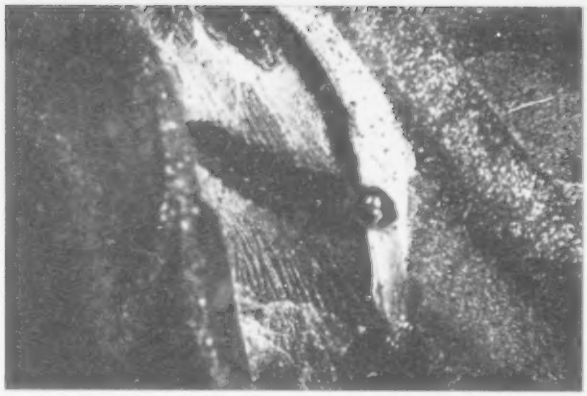


PLATE 91. Closeup of larvae.

PLATE 92. Fruit damage caused by tomato pinworm.

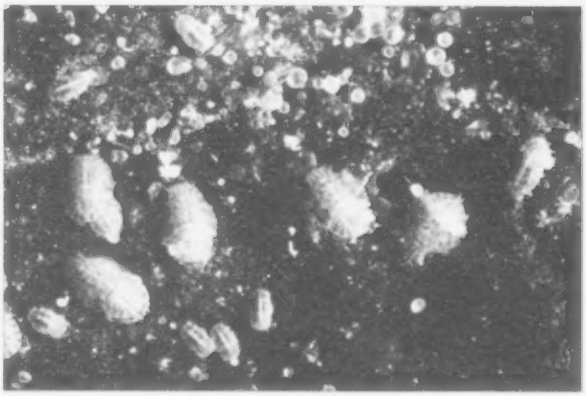


PLATE 93. Nymphal stages of potato psyllids.

PLATE 94. Leafminer damage on tomato.

Emergency and First-Aid Procedures for Pesticide Poisoning

For a major spill, a theft or a fire involving a pesticide call the Ministry of the Environment at **1-800-268-6060**.

For pesticide poisonings and pesticide injuries call the **Poison Information Centre**:

Toronto	1-800-268-9017
Ottawa (Bilingual)	1-800-267-1373
Hearing Assistance (TTY)	1-877-750-2233

PREVENT ACCIDENTS

- **Read the label**. Follow all the precautions the label recommends. Read the First Aid section of the label BEFORE you begin to handle any pesticide.
- **Make sure that someone knows** what pesticides you are working with and where you are.
- **Keep a file of labels and product Material Safety Data Sheets (MSDS) for the pesticides you use**. Make sure everyone knows where to find this in case of an emergency.
- **Post emergency numbers near all telephones.**
- **Keep clean water, paper towels, extra gloves and clean coveralls close by** in case you spill pesticide on yourself.

If someone has been working with pesticides and you see any possible symptoms of pesticide poisoning or **injury, take emergency action immediately.**

IF AN ACCIDENT OR POISONING HAPPENS

- Protect yourself from injury first.
- Stop the exposure to the pesticide. Move the victim away from the contaminated area.
- Check the 4 basic facts — identify the pesticide, the quantity, the route of entry and time of exposure.
- Call an ambulance or the Poison Information Centre.
- Start first aid. This is **not** a substitute for professional medical help.
- **Provide the label, MSDS sheet or container to emergency personnel** at the scene — or take it with you to the hospital. Do not transport pesticide containers in the passenger compartment of the vehicle.

FIRST AID

If a pesticide comes in contact with skin:

- remove all contaminated clothing; wash skin thoroughly with lots of soap and warm water
- dry skin well and cover with clean clothing or other clean material.

If pesticide comes in contact with eyes:

- hold eyelids open wash the eyes with clean running water for 15 minutes or more.

If pesticide was inhaled:

- move the victim to fresh air and loosen tight clothing
- give artificial respiration if the victim is not breathing.

Do not breathe in the exhaled air from the victim — you could also be poisoned.

If a pesticide was swallowed:

- **call the Poison Information Centre IMMEDIATELY.**

Emergency numbers are listed at the front of each Bell telephone directory.

For information, or to obtain copies of this or any other ministry publication please:
call 1-888-466-2372 from within Ontario,

(519) 826-3700 from outside the province or OMAF's TTY line at (519) 826-7402 for the hearing impaired, email your request to *products@omaf.gov.on.ca*, or visit OMAF's web site at *www.omaf.gov.on.ca*.

A complete list of all OMAF products and services, and order forms, are available on the web site. Orders can be faxed to (519) 826-3633 or mailed to Government Information Centre,
1 Stone Road West, Guelph, Ontario N1G 4Y2.

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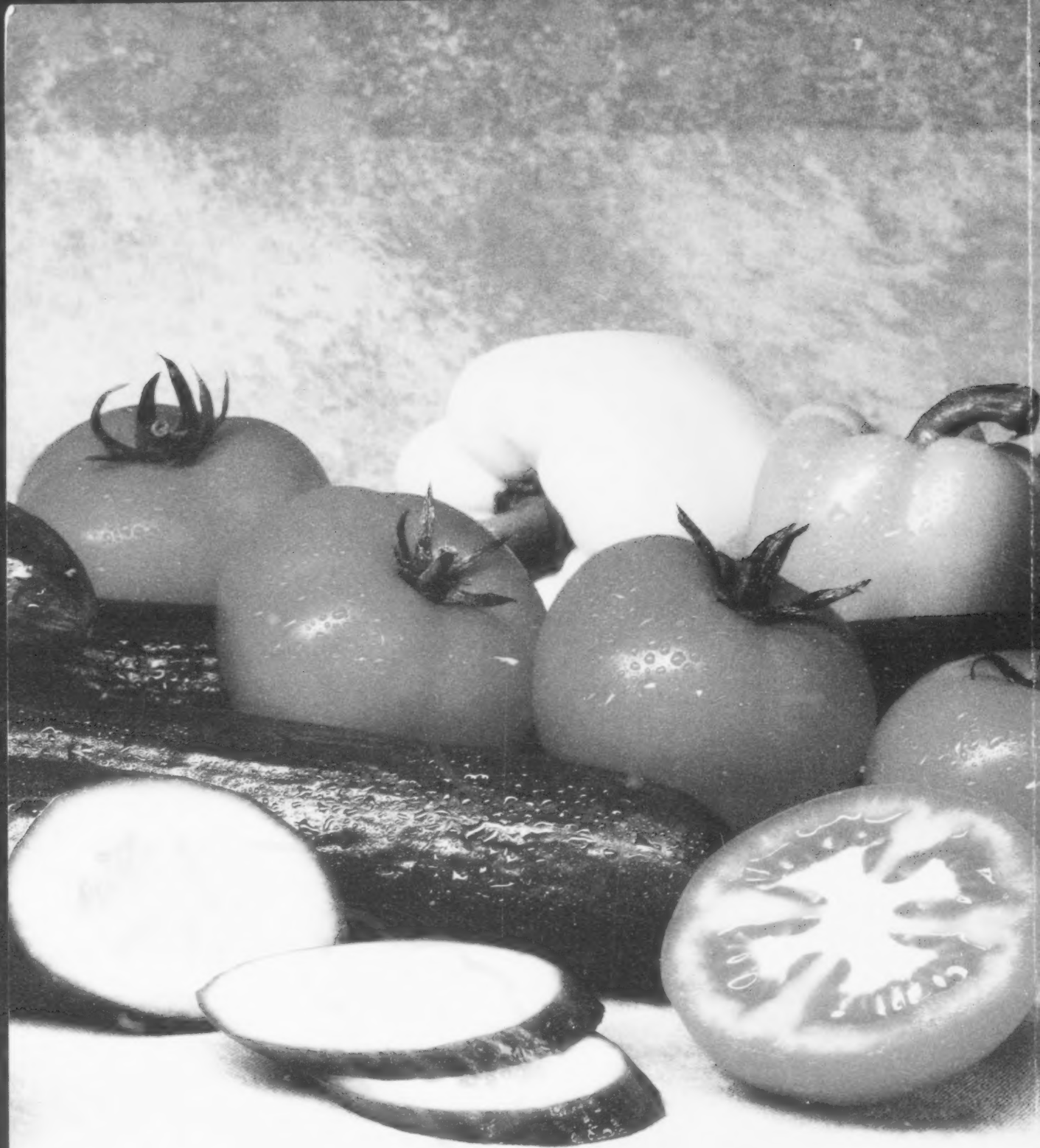

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